LAMONT-DOHERTY GEOLOGICAL OBSERVATORY
COLUMBIA UNIVERSITY
PALISADES, NEW YORK

PRECISION SOUND VELOCITY PROFILES IN THE OCEAN

VOLUME V

SOUND SPEEDS AND TEMPERATURES OF BERMUDA WATERS IN AUTUMN AND WINTER (October 1964 - March 1966)

by

Ants T. Piip

Columbia University Geophysical Field Station
St. David's, Bermuda

Technical Report No. 7
CU-7-69

Submitted to Acoustic Programs, Office of Naval Research under Contract Nonr 266 (65).

October 1969

ABSTRACT

A collection of high-resolution, precision simultaneous sound speed and temperature profiles to 2200m depth, and their envelopes for each station is presented for 25 stations in Bermudian waters in the months of October,December and March. The period October to March covers the full range of large seasonal changes in the near-surface waters from summer to winter;while the deep waters remain relatively stable and do not show any definite seasonal changes. For two long constant depth stations, in and below the main thermocline, time series and their power density spectra are shown for sound speeds and temperatures. A table of sound channel parameters at all stations concludes the report. The report emphasizes the variability and short-lived phenomena in oceanic waters around Bermuda.

TABLE OF CONTENTS

LIST OF STATIONS AND FIGURES

Chart of Stations: Fig. 1.

STATION NUMBER	POSITION North	West	DATE	# OF PROFILES		FIGURE NUMBER PROFILES SOUND SPEED	TEMPERATURE	ENVELOPES
40	31°35'	64°35'	1 Oct. 64	4		2	3	56
41	30°37'	64°37'	2-5 Oct. 64	22		4	5	57
	Constant Depth Recordings:			depth 1170m (41CD1):		6; Spectrum: 8		
				930m (41CD2):		7; Spectrum: 9		
42	30°37'	64°35'	10/11 Oct. 64	8		10	11	58
43	32°23'	64°28'	2 Dec. 64	2		32	33	63
45	32°18'	64°25'	6 Dec. 64	4		34	35	64
46	31°42'	64°41'	13 Dec. 64	2		36	37	65
47	31°54'	64°12'	13 Dec. 64	2		38	39	66
48	32°13'	64°28'	17 Dec. 64	2		40	41	67
86	32°52'	63°55'	13/14 Dec. 65	4		42	43	68
87	32°22'	63°40'	14 Dec. 65	2		44	45	69
88	31°58'	64°00'	16/17 Dec. 65	4		46	47	70
89	31°45'	64°44'	17 Dec. 65	4		48	49	71
90	31°42'	64°37'	22 Mar. 66	4		50	51	72
91	32°02'	64°37'	23 Mar. 66	2		52	53	73
92	32°02'	64°37'	25 Mar. 66	2		54	55	74
109	32°13'	64°30'	13 Oct. 66	2		12	13	59
110	32°14'	64°25'	18 Oct. 66	2	"Circle around Bermuda"	14	15	60,61
111	31°34'	65°21'	19 Oct. 66	4		16	17	"
112	32°17'	65°53'	20 Oct. 66	4		18	19	"
113	33°01'	65°16'	21 Oct. 66	4		20	21	"
114	32°58'	64°25'	22 Oct. 66	6		22	23	"
115	32°58'	63°26'	22 Oct. 66	4		24	25	"
116	32°17'	63°56'	22 Oct. 66	5		26	27	"
117	31°34'	64°26'	23 Oct. 66	4		28	29	"
119	32°14'	64°34'	10 Nov. 66	2		30	31	62

INTRODUCTION

This volume presents a collection of high-resolution, precision simultaneous sound speed and temperature versus depth profiles from 25 stations taken in Bermudian waters during the months of October, December and March of several years. The time between October and March encompasses nearly the full range of seasonal changes in the ocean around Bermuda.

In October the surface waters around Bermuda still retain their summer character, with a very warm and shallow surface layer. By March they have reached their full winter structure where the topmost several hundred meters are nearly isothermal. December is intermediate in character, the thin warm water layer has disappeared from the surface, the isothermal region only reaches to about a hundred meters. At greater depths, the bottom of the 18° Sargasso Sea (i.e., the main thermocline) shows some seasonal changes, but these are not very drastic.

In addition to showing profiles, we have included two sound speed and temperature time series at constant depths, one just below, the other inside the main thermocline, and their power density spectra. This data was obtained during a long anchor station in over 2000 fathoms depth, about 100 miles south of the island.

INSTRUMENTATION, DATA PROCESSING

All stations in this report were taken from our R/V SIR HORACE LAMB, using several generations of our sound velocimeter instrument package and associated shipboard recording gear. Although the instrumentation at different times might have differed in detail, the principles and methods have remained unchanged over the years.

The underwater sensor package contained two NBS-type velocimeters (Modified TR-2) for channels 2 and 3; a FM-output precision pressure gauge for channel 1; and a FM-output platinum resistance thermometer (Hytech 4002) in channel 4. Each instrument was fed by an individual voltage regulator. The instrument outputs, after suitable frequency divisions to prevent overlapping, and filtering, were combined in a summing cable driver amplifier and sent up via a single-conductor cable. The underwater package was powered from a topside constant-current DC supply through the same cable.

On shipboard the composite signal was separated into its component channels. The frequencies were multiplied by a chain

of push-push doublers to four times the basic instrueumnt frequencies in order to improve resolution. The 4 channels were scanned and counted in a 1-2-1-3-1-4 sequence, a second for each channel, and the frequencies printed on paper tape.

In profiling, cable speed was controlled to give a depth change rate of about 1 m/s. Thus, sound speed readings were obtained about every 3.5m, temperature every 9m, and depth every 3m, on the average.

Our methods of data processing ashore, and quality control, have been described in previous volumes of this series. Suffice to mention that data reduction was done on the LDGO computer, yielding machine-drawn original profiles as well as numerical output data; and that the sound speed as given in the graphs is the validated average of the two velocimeter readings.

ACCURACY, CORRECTIONS TO THE PLOTS

The sound speeds in the graphs pertain to a velocimeter standardized for + 10°C. For other ambient temperatures, the readings in the plots have to be corrected for sound path expansion effects:

True sound speed = V_i + Correction

Correction = $1.46 \cdot 10^{-5} (T - 10) V_i$

where T: ambient temperature, °C

and V_i: indicated sound speed

T, °C	Correction, m/s
25	+ 0.33
20	+ 0.22
15	+ 0.11
10	0.00
5	- 0.11
0	- 0.22

Depths in this report are true, corrected values.

Conservative estimates of the quality of our data are as follows:

	Total uncertainty, absolute	Reproducibility, resolution
Sound speed	± 0.15 m/s	± 0.10 m/s
Temperature	± 0.05 °C	± 0.03 °C
Depth	± 5m ± ½% ≤ ± 10m	± 2.5m ± ¼% ≤ ± 5m

The sound speed uncertainties are relative to the standard used in laboratory calibration of our velocimeters (Greenspan & Tschiegg. 1957). These tables were used as published, although it is generally believed they are too high by about 0.3 m/s (C.E. Tschiegg, NBS, 1966, personal communication).

ORGANIZATION OF PLOTS

Figure 1 is a chart of our stations. Since the character of the oceanic water structure really depends only on the time of the year, the seasonal changes being repeated with minor variations from year to year, we have grouped our stations according to months: October '64 and '66, December '64 and '65, and March '66.

There are three figures for each station: 1) the individual, consecutive sound speed profiles, 2) the individual, consecutive temperature profiles, and 3) sound speed and temperature profile envelopes, showing the total spread of either quantity over the duration of the station.

The individual profiles have been spaced by 5 m/s, or 2 $^{\circ}$C to improve legibility (except in very long stations, where the spacing is smaller). Each profile carries marks at round sound speed or temperature values, e.g. 1495,1500, 1505 m/s, etc.; or 5, 10, 15 $^{\circ}$C, etc. The small horizontal ticks on the sound speed profiles are 10-minute time marks: the times and depths for each tick are listed in the Appendix "Timing of Profiles".

Temperature and sound speed profile envelopes are given in the same figure: temperature at left, sound speed at right. An exception is Stations 111 - 117 which constitute a near-synoptic survey of the waters around the island, on a circle about 60 miles radius: for these stations all temperature envelopes have been combined in one figure, sound speeds in another — in order to present a better "snapshot" of the hydrography around the island.

All profiles have been reproduced on a uniform scale: 100m depth = 0.2 inches; 1 m/s = 0.1 inches: 1 $^{\circ}$C = 0.2 inches. An easy way to read the profiles is to prepare a transparent overlay of 10 x 10 to the inch graph paper.

RESULTS

I. STATIONS 40-42 , 109-119: OCTOBER

The shallower portions of the two October series are quite different. The 1964 stations, taken early in the month, are typical summer profiles: uniformly increasing temperature near the surface, from about 100m upwards, with occasional near-isothermal patches. The upper knee of the main thermocline (more precisely, the knee in the sound speed profiles: a combined effect of the thermocline knee and the mild salinity maximum above it) is at roughly 400m depth.

The 1966 stations, taken towards the end of the month, already show an autumnal water structure: a well-defined, 50m thick isothermal surface layer, and the upper knee of the thermocline has sunk to 500m depth.

This summer-autumn transition occurs around Bermuda during September or October — sometimes earlier, sometimes later, depending largely on the local weather.

At depths beyond 500m, no real differences can be observed between the two years.

In 1964 we were mainly concerned with the stability of the sound channel, thus most of the profiles in these three stations (40,41,42) do not reach into the surface waters. Instead, there are long series of consecutive profilings in and below the thermocline. Stations 41 and 42 were anchor stations. (Our technique of anchoring at depths over 2000 fathoms has been described in Volume III of this series.)

IA. Station 41: CONSTANT DEPTH RECORDINGS IN AND BELOW THE THERMOCLINE: INTERNAL WAVES AND THEIR SPECTRA *

In station 41 we tried to take a close look at the internal waves around the main Sargasso Sea thermocline. We anchored the ship in over 2000 fathoms of water about 100 miles south of Bermuda and started our station by taking half a dozen profiles to a little over 2000m depth. (Figs. 4, 5.) These showed that the waters were normal, no large cells or thick layers were to be seen anywhere, except a medium-sized one around 1000m, and the currents were no stronger than usual.

We stopped our instruments on the sound channel axis, below the lower knee of the main thermocline, and kept them there for the next 30 hours at a depth of 1167 $\pm$ 2 meters (41CD1). This was followed by 12 profiles of the usual kind, after which we had another constant-depth session, inside the thermocline but still close to the lower knee at 923 $\pm$ 2 meters (41CD2). After 18 hours at this depth, the weather worsened and we had to terminate our station.

During the constant depth periods we slowed down our sampling rate to 80 seconds for a complete depth-temperature-sound speed reading sequence — a compromise between amount of digital data gathered and high-frequency resolution.

Total recording time on station was 77 hours.

---

* Condensed from "Internal Waves In and Below the Sargasso Sea Thermocline", presented as paper O-43 at the 50th Annual Meeting of the American Geophysical Union, Washington, D. C., April 1969.

Figures 6 and 7 show the results of our constant depth sessions, depth, temperature and sound speed versus time: Fig.6 below the thermocline, Fig. 7 inside the thermocline. (NB: Vertical scales of the two figures are not the same.)

The actual constant-depth parts of the two sessions have been extended in time by taking readings at the proper depths from our profiles before and after the constant depth parts. These very low resolution "wings" help to extend our observation times for very long period waves.

The two time series show immediately the near-perfect correlation between the temperature and sound speed traces. The amplitudes of these two traces are an order of magnitude larger than could be caused by depth variations alone — we are seeing internal waves, an up-and-down fluctuation of the water mass. These oscillations are a combination of a true up-and-down oscillation of the waters, plus some current effects. The latter are probably small compared to the first.

The maximum temperature and sound speed variations observed over the duration of our station are 0.25 ^{o}C (1.1 m/s) below the thermocline (Fig. 6). Inside the thermocline (Fig.7), the variations are nearly twice as much: 0.44 ^{o}C (1.86 m/s). Comparing these figures to the mean gradients at the depths of measurement ($1.25 \cdot 10^{-2}$ ^{o}C/m at 920m; $0.6 \cdot 10^{-2}$ ^{o}C/m at 1170m), we can infer wave amplitues of at least 32 meters inside the thermocline, 40 meters just below it. Nothing definite can be said about the periods of these large slow waves, although there are indications they might be close to tidal. Our samples really are not long enough to let us decide, but the very washed-out peaks in the time series tracings are separated by intervals which look roughly diurnal and semidiurnal. The major peaks do not coincide with surface tide extremes, they fall about half-way between.

In addition to the slow large waves both time series show complex, random more rapid oscillations of varying amplitude and periodicity. No persistent or dominant frequencies can be seen in either recording. Occasionally quite distinct single-frequency wavetrains can be discerned — they are of very short duration, of a few periods each. These short single-frequency wavetrains are more common inside the thermocline than below it.

The two constant-depth time series have been spectrally analyzed for power density, using the standard technique of taking the autocorrelation function of the time series and Fourier transforming this into the frequency domain.(Blackman & Tukey,1959; Hassell, 1965; Onyx, 1966; Richards, 1967) The first, fairly obvious result of the analysis is that the time series at both depths are not yet stationary for our observation times, 18 and 30 hours. Considering the very long periods of the large waves involved, series of at least a week or more might tend to become stationary. Even then we would probably have to eliminate seasonal changes from the analysis.

Because of the shortness and non-stationarity of our time series, we cannot claim any general validity of our power density spectra — they should only be considered illustrative, typical of relatively short periods of observation.

Two different windows were tried in our analysis: a narrow v. Hann window (weighting coefficients 0.25 + 0.50 ÷ 0.25), and an approximately 8 minutes wide modification (0.05 + 0.1 + 0.2 + 0.3 + 0.1 + 0.05) of the same for a wider passband. The results of the two windows are similar, but at the time of this writing we cannot give an explanation why the two windows produce different slopes in the low-frequency part of the spectra.

The power density spectra of our two depths (Figs. 8, 9) are superficially similar, but differ significantly in detail. In both cases power decreases with increasing frequency, both can be divided into three regions: a steep drop at low frequencies, an intermediate region, and a flat high-frequency tail.

The "intermediate region" is more or less centered around the local Väisälä frequency — the high frequency limit of propagating internal waves. This limit is directly proportional to the square root of the mean local density gradient.

Waves do occur at frequencies higher than this limit, but they do not travel very far, they suffer considerable attenuation and are soon lost. These high-frequency waves have either leaked from an adjoining region of high density gradient, or they can originate locally at thin interlayer boundaries. In the latter case their energy and amplitudes would be quite small.

Our power spectrum from below the thermocline (Fig. 8)shows these regions and relationships in a very clear fashion. At the low frequency end there is a rapid dropoff in energy until we reach the deep water Väisälä frequency at about 0.6 periods per hour. These are the slow, high amplitude waves which involve very large and thick water masses, and can propagate unhindered anywhere in the ocean. The frequency-power relationship of the wide window spectrum in this region is close to the 5/3 power law.

The "intermediate" region in this deep spectrum fits perfectly between the Väisälä frequencies for deep water and the mean thermocline. The local Väisälä frequency is 1.3 periods per hour, halfway between the deep waters and the thermocline. This is not very surprising — we are still very close to the thermocline, close enough for a large amount of the high-frequency waves, which are permissible in the thermocline, to leak down.

The spectral power in this region decreases approximately with frequency to the power of -4/3.

Above the high-frequency break in this spectrum there is a very weak, practically flat tail.

Figure 9 seems to indicate that the relationships inside the thermocline, a little above its lower knee, are not as clearcut as 250m deeper. We probably can blame our much shorter recording time for some of this.

Again, there is a sharply dropping low-frequency section which more-or-less follows the 5/3 law. At a frequency close to 1 per hour this levels off to a nearly level, "white" intermediate region reaching to 5 or 6 periods per hour, a little above the high-frequency limit of the thermocline as a whole. The local Väisälä frequency, 3 per hour, is again near the center of this region. At periods shorter than 12 minutes there are several minor peaks in the spectrum, at non-harmonically related frequencies. We suspect these are caused by small local oscillations of high-gradient interfaces between layers of slightly different waters — the individual temperature and sound speed profiles are quite wiggly at this depth. Inside the thermocline, temperature gradients of the order of 1/4 °C/m can be found at thin interlayer boundaries — the Väisälä period for such a high gradient is of the order of 5 minutes. It is hard to believe the oscillations in the spectrum are caused by aliasing or noise, since recording quality and conditions for this constant depth session were identical to the first one.

IB. STATIONS 111-117: CIRCLE AROUND BERMUDA .

In October 1966 we made a 5-day series of stations around Bermuda, equally spaced at about 60 miles distance from the islands. The sound speed and temperature profile sequences are shown in Figs. 14-29; the combined envelopes for the whole series in Figs. 60 and 61.

Each of the stations consisted of 4 consecutive profiles, except Station 114: there we took 6 profiles since the quick-look shipboard XY recorder showed a large water mass rapidly moving in between profiles 2 and 3 (Figs. 22, 23), in the middle of the main thermocline. One does not often meet large, over 100m thick water cells in the thermocline proper, and even more unusual is the cold character of this cell. In approximately one hour this cell had attained its full concentration. It lifted the 12 °C isotherm by about 50m, or reduced the temperature at 700-800m depth by a full degree C. A quick look at the depth-sound speed-temperature relations, by reversing Wilson's sound speed formula, shows this cell (profile 3) to have a nearly 0.3% salinity deficiency compared to our profile 2. Between our profiles 3 and 6 the cell was gradually sinking deeper and growing less and less distinct. By the end of the station it was barely noticeable.

We do not have any accurate data on the ship's motions,even relative to the water, during the station, but any reasonable assumption about currents and drifts yields a lateral size of the cell of the order of a very few miles, say 3-5 at most.There are no signs of the cell in the neighbor stations (113,115,116).

Concurrently with the cold mass at 600-800m there were two warm water masses appearing in the same station, at both knees of the thermocline: at 300-400m and 1100-1300m depth. These were not by far as prominent as the central cold cell.

The two southernmost stations (111,117) of our circle differ from the others by having a much lower minimum sound speed at the sound channel, and a main thermocline about 50m shallower than the rest between 5 ^{o}C and 15 ^{o}C. If we postulate a deep current coming from the North, we could explain this deformation as a rolling-up of the thermocline by the wake of the island pedestal. (Station 110, too close to the island and in its shadow, shows a normal thermocline).

With the exception of the three stations discussed in detail, there is not much that can be said about the other stations: their differences are negligible. The only signicicant difference is the high surface and mixing layer temperature in the southeastern stations (111,112), and close to the island (110).

IC. 15^{o} ISOTHERMAL WATER, STATION 119.

Station 119, two weeks after "the circle", has been included because of its unusual temperature structure between 350 and 800m depth. The well-defined isothermal 14.8 ^{o}C water between 550-800m is seen occasionally in summer and autumn just below the 18^{o} water, and seems to be sharply defined cell of short apparent lifetime, indicating small lateral dimensions of the cell and rapid transport by currents at this depth.

The two sharply defined, thin cold layers at 400m we have only seen in this particular station. We have no idea of their source, lifetime or lateral dimensions.

II. STATIONS 43-48, 86-89: DECEMBER.

All these December stations show a typically autumnal surface water structure: a nearly isothermal, about 100m thick surface layer. The bottom part of this layer is quite variable and probably patchy: in some of the stations the knee of the sound speed profiles is very sharp, in some quite round and gradual.

The surface waters in 1965 were appreciably more variable than in '64, in spite of the shorter time span covered. Station 88 is interesting: over the duration of the station there is a progressive cooling of the surface proper, and a radical shape change of the uppermost 100m between profiles 1 and 2. Our interpretation is that we were observing the edge of a patch of "abnormal" surface waters in profile 1.

Deeper down, the differences between the two years are very small. The main difference is that the deep waters, under the main thermocline, were a trifle colder in 1965 than in 1964. As a consequence, the sound channel was slightly shallower in 1965 than in 1964, and its minimum sound speed was slightly lower.

III. STATIONS 90-92: MARCH.

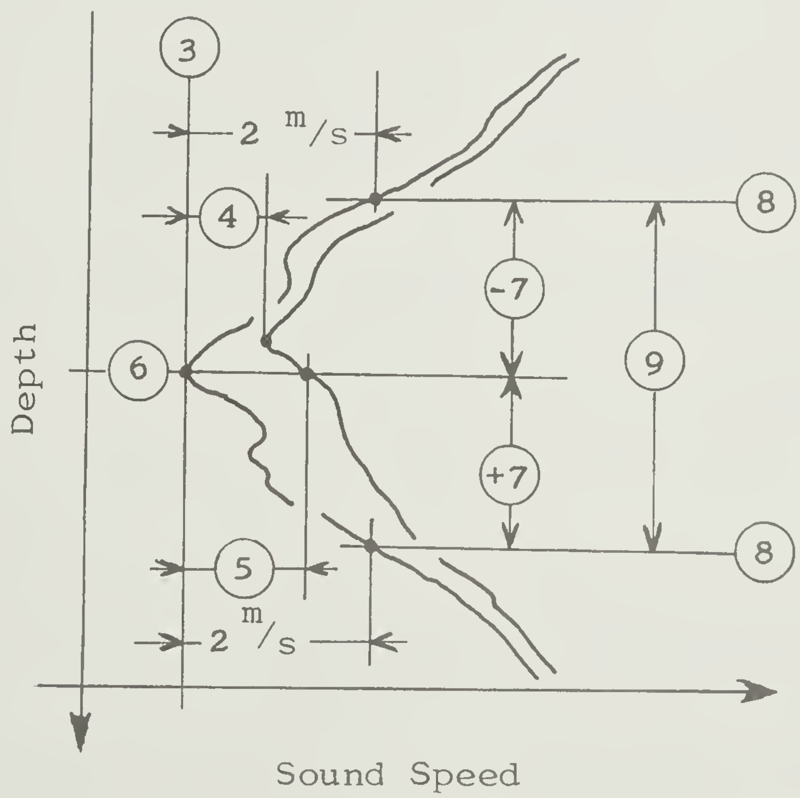
These three stations show typically winter surface waters: the warm mixed layer has disappeared, the top-most 200m are nearly isothermal (18.5-18.8^{O}C), rather variable and probably patchy. In all cases, however, there is a very pronounced acoustic duct at the surface.

The only interesting feature worth mentioning in the deep waters is the rapid rise of temperatures between profiles 2 and 3 of station 90, at depths between 800 and 1300m.

TABLE 1: SOUND CHANNEL PARAMETERS.

Table 1 attempts to give a numerical description of the sound channel region and its variability for all stations. This table is based on readings from the composite sound speed profile envelopes at each station.

The columns in the table are defined as follows (circled numbers in sketch correspond to column headings):



Column 1: Station number.

Column 2: Mean sound speed at 1500m depth.

Column 2A: Mean sound speed at 2000m depth.

Column 3: The axis or minimum minimum sound speed is the lowest speed in the composite profile envelope.

Column 4: The sound channel width is defined as the difference of the minima of the high speed (right-hand) and low speed (left-hand) contours of the composite envelope. These minima do not necessarily occur at the same depth, they can be separated by several hundred meters.

Column 5: Variability at the sound channel axis. Defined as the width of the composite envelope at the depth of the minimum minimum sound speed.

Column 6: Axis depth: The depth at which the minimum minimum sound speed occurs.

For columns 7, 8, 9, we have arbitrarily defined the sound channel as the region between points on the low speed (left-hand) side of the composite envelopes, having a sound speed 2 m/s higher than the minimum minimum speed.

Column 7: Vertical spread of the upper and lower boundaries of the sound channel, up and down from the minimum minimum speed (axis) depth.

Column 8: Depths of the upper and lower boundaries of the sound channel.

Column 9: Total vertical extent of the sound channel.

Column 10: Duration of station, hours.

ACKNOWLEDGEMENTS

This work was performed under the aegis of Acoustics Programs, Code 468, U. S. Office of Naval Research.

Thanks are due to my colleagues and collaborators at the Columbia University Geophysical Field Station, particularly Brian Turner, and Capt. McCann and the crew of our R/V SIR HORACE LAMB.

REFERENCES

R. B. Blackman and J. W. Tukey, 1959: "The Measurement of Power Spectra from the Point of View of Communications Engineering". Dover Publications, New York.

M. Greenspan and C. E. Tschiegg, 1957: "Speed of Sound in Water by a Direct Methos", J. Res. Nat. Bur. Stds. 59, 249.

B. C. Hassell, 1965: "Autocorrelation and Power Spectrum Analysis", USNUSL Technical Memorandum No. 913-52-65.

P. Onyx, 1966:"Correlation Program", USNUSL Technical Memorandum No. 2070-223-66.

P. I. Richards, 1967: "Computing Reliable Power Spectra", IEEE Spectrum 2, 83-90.

TABLE I

SOUND CHANNEL PARAMETERS

	1	2	2A	3	4	5	6	±7	8	9	10
	Station number	Mean sound speed at 1500m depth	Mean sound speed at 2000m depth	Axis (min. min.) sound speed	Sound channel width (min. max. - min. min.)	Variability at axis depth	Axis (min. min. s.s.) depth	S. channel spread, up and down from axis	Sound channel depth limits	Vertical extent of sound channel	Station duration
	#	m/s	m/s	m/s	m/s	m/s	m	m	m	m	h
OCTOBER '64	40	1493.4	1499.3	1491.5	1.0	2.1	1250	-220 +210	1030 1460	430	7
	41	1494.6	------	1492.9	1.8	3.0	1110	-140 +360	960 1470	510	77
	42	1494.5	------	1492.9	0.7	1.1	1200	-225 +340	975 1540	565	28
OCTOBER '66	109	1493.3	1499.6	1492.2	0.1	0.1	1320	-260 +250	1060 1570	510	4
	110	1493.2	1499.6	1492.3	0..2	0.5	1240	-175 +360	1065 1600	535	2
	111	1493.0	1499.2	1491.0	0.2	0.4	1240	-210 +270	1030 1510	480	3
	112	1493.3	1499.6	1492.9	0.5	0.6	1310	-240 +290	1070 1600	530	5
	113	1494.0	1500.2	1493.1	0.7	1.2	1310	-230 +310	1050 1590	540	5
	114	1493.8	1499.6	1492.2	0.3	0.6	1240	-160 +320	1080 1560	480	7
	115	1493.5	1499.8	1492.9	0.2	0.7	1280	-220 +290	1060 1570	510	4
	116	1493.4	1499.4	1492.4	0.5	0.6	1240	-150 +350	1090 1590	500	8
	117	1493.0	1499.2	1490.6	1.0	1.0	1180	-180 +310	1000 1490	490	5
	119	------	-------	1492.4	0.2	0.2	1280	-180 ----	1100 ----	---	2
DECEMBER '64	43	1493.1	-------	1492.0	0.1	0.1	1260	-235 +340	1025 1600	575	2
	45	1493.2	1499.0	1491.8	0.6	0.7	1240	-155 +280	1085 1520	435	3
	46	1492.8	------	1491.3	0.1	0.1	1285	-165 +275	1120 1560	440	1
	47	1493.2	------	1492.2	0.3	0.5	1285	-265 +315	1020 1600	580	1
	48	1493.0	------	1492.8	0.4	0.6	1270	-270 +315	1000 1585	585	2
DECEMBER '65	86	1493.0	1499.5	1491.4	1.1	2.4	1180	-150 +315	1030 1495	465	6
	87	1494.8	1499.4	1490.6	0.1	0.1	1190	-220 +310	970 1600	530	3
	88	1492.6	1499.2	1491.6	0.7	1.1	1255	-220 +290	1035 1545	510	7
	89	1492.8	1499.2	1492.0	1.5	2.0	1190	-130 +290	1060 1480	420	6
MARCH '66	90	1492.4	1499.4	1491.3	1.3	1.4	1250	-290 +380	1020 1630	610	6
	91	1495.2	1499.6	1493.6	0.3	0.4	1130	-260 +480	970 1710	740	3
	92	1495.5	1499.4	1493.8	0.3	0.4	1100	-210 +470	990 1670	680	3

APPENDIX
Timing of Profiles

Profile	D(m)	GMT	Profile	D(m)	GMT	Profile	D(m)	GMT	Profile	D(m)	GMT
40/1	595	2020	41/1	1	1625	41/5	844	2300	41/10	1165	1040
	759	2030		65	1630		981	2310		885	1050
	1000	2040		241	1640		1168	2320		702	1100
	1289	2050		383	1700		1397	2330		647	1103
	1502	2100		564	1710		1502	2340	41/11	646	1103
	1740	2110		794	1720		1574	2350		720	1110
	1767	2111		1046	1730		1675	2400		960	1120
40/2	1769	2113		1277	1740		1792	0010		1202	1130
	1738	2120		1432	1750		1892	0019		1420	1140
	1668	2130		1613	1800	41/6	1894	0022		1619	1150
	1574	2140		1862	1810		1793	0030		1804	1200
	1471	2150		1893	1813		1644	0040		1890	1206
	1354	2200	41/2	1894	1819		1474	0050	41/12	1894	1220
	1213	2210		1889	1820		1286	0100		1774	1230
	1060	2220		1701	1830		1082	0110		1618	1240
	898	2230		1464	1840		840	0120		1459	1250
	713	2240		1228	1850		638	0127		1304	1300
	508	2250		1038	1900	41/7	636	0129		1150	1310
	372	2256		871	1910		640	0130		996	1320
40/3	373	2259		695	1920		803	0140		831	1330
	381	2300		648	1923		968	0150		651	1340
	593	2310	41/3	645	1925		1111	0200	41/13	642	1357
	850	2320		696	1930		1147	0203		658	1400
	1068	2330		833	1940	41CD1	1168	30hr.		779	1410
	1325	2340		964	1950	(Constant Depth)				896	1420
	1568	2350		1064	2000	41/8	1162	0815		1015	1430
	1867	2400		1167	2010		1100	0820		1109	1440
	2064	0010		1313	2020		927	0830		1214	1450
	2169	0015		1370	2030		731	0840		1319	1500
40/4	2169	0030		1533	2040		636	0844		1460	1510
	2109	0040		1753	2050	41/9	637	0845		1606	1520
	2035	0050		1895	2055		690	0850		1790	1530
	1950	0100	41/4	1895	2113		892	0900		1895	1536
	1822	0110		1830	2120		1085	0910	41/14	1894	1552
	1636	0120		1736	2130		1195	0920		1815	1600
	1432	0130		1586	2140		1335	0930		1643	1610
	1213	0140		1406	2150		1480	0940		1458	1620
	997	0150		1243	2200		1668	0950		1256	1630
	830	0200		1096	2210		1870	1000		1060	1640
	655	0210		945	2220		1893	1002		867	1650
	455	0220		785	2230	41/10	1891	1004		654	1700
	229	0230		641	2238		1763	1010		640	1701
	1	0240	41/5	642	2242		1592	1020			
				712	2250		1394	1030			

APPENDIX (Cont.)
Timing of Profiles

Profile	D(m)	GMT
41/15	636	1706
	673	1710
	814	1720
	917	1730
	1018	1740
	1106	1750
	1200	1800
	1288	1810
	1401	1820
	1543	1830
	1670	1840
	1789	1850
	1894	1858
41/16	1898	1903
	1813	1910
	1646	1920
	1472	1930
	1281	1940
	1074	1950
	837	2000
	626	2008
41/17	629	2014
	738	2020
	965	2030
	1164	2040
	1356	2050
	1533	2100
	1701	2110
	1863	2120
	1895	2122
41/18	1895	2124
	1841	2130
	1656	2140
	1448	2150
	1220	2200
	1042	2210
	906	2220
	757	2230
	591	2240
	396	2250
	295	2258
41/19	297	2258
	334	2300
	579	2310
41/19	731	2320
	874	2330
	1012	2340
	1133	2350
	1262	2400
	1427	0010
	1610	0020
	1786	0030
	1894	0038
41/20	1894	0043
	1831	0050
	1724	0100
	1588	0110
	1435	0120
	1267	0130
	1084	0140
	972	0150
	839	0200
	694	0210
	533	0220
	329	0230
	296	0231
41/21	296	0241
	464	0250
	687	0300
	868	0310
	908	0314
41CD2	924	17hr.
(Constant Depth)		
41/22	922	2057
	538	2100
	1	2110
42/1	1	1715
	67	1720
	230	1730
	375	1740
	381	1750
	629	1800
	803	1810
	1045	1820
	1194	1830
	1285	1835
42/2	1278	1848
	1265	1850
	1180	1900
	1111	1910
	1003	1920
	868	1930
	767	1940
	628	1950
	401	2000
	335	2010
	149	2020
	1	2029
42/3	1	2040
	125	2050
	265	2100
	374	2110
	415	2120
	592	2130
	776	2140
	898	2150
	1076	2200
	1194	2210
	1316	2220
	1450	2230
	1673	2240
	1905	2250
42/4	1901	2250
	1788	2300
	1586	2310
	1347	2320
	1253	2330
	1125	2340
	1024	2350
	868	2400
	765	0010
	587	0020
	362	0030
42/5	363	0034
	419	0040
	536	0050
	669	0100
	839	0110
	1005	0120
	1204	0130
42/5	1315	0140
	1438	0150
	1569	0200
	1723	0210
	1753	0214
42/6	1752	0217
	1733	0220
	1644	0230
	1534	0240
	1414	0250
	1307	0300
	1191	0310
	1067	0320
	931	0330
	785	0339
42CD1	775	12hr.
(Constant Depth)		
42/6A	777	1600
	694	1610
	589	1620
	484	1630
	378	1640
42/7	372	1644
	430	1650
	550	1700
	651	1710
	744	1720
	850	1730
	979	1740
	1086	1750
	1183	1800
	1269	1810
	1339	1820
	1444	1830
	1528	1840
	1642	1850
	1758	1858
42/8	1759	1902
	1702	1910
	1615	1920
	1518	1930
	1419	1940
	1309	1950
	1190	2000

APPENDIX (Cont.)
Timing of Profiles

Profile	D(m)	GMT
42/8	1040	2010
	860	2020
	631	2030
	343	2040
	309	2050
	165	2100
	1	2108
43/1	10	1340
	470	1350
	967	1400
	1529	1410
	1764	1419
43/2	1754	1422
	1358	1430
	1082	1440
	629	1450
	159	1500
	1	1505
45/1	1	1628
	31	1630
	479	1640
	1008	1650
	1388	1700
	1919	1710
	2025	1711
45/2	2001	1720
	1543	1730
	1103	1740
	677	1750
	234	1800
	1	1808
45/3	1	1809
	37	1810
	500	1820
	759	1830
	1121	1840
	1415	1850
	1688	1900
	1965	1903
45/4	1905	1917
	1781	1920
	1513	1930
	1324	1938

Profile	D(m)	GMT
46/1	4	0427
	98	0430
	488	0440
	1006	0450
	1399	0500
	1901	0508
46/2	1899	0510
	1423	0520
	830	0530
	287	0540
	1	0546
47/1	1	0919
	17	0920
	369	0930
	766	0940
	1327	0950
	1889	0958
47/2	1895	1001
	1543	1010
	948	1020
	321	1030
	1	1036
48/1	3	1629
	13	1630
	285	1640
	598	1650
	851	1700
	1212	1710
	1485	1720
	1767	1730
	1935	1737
48/2	1936	1739
	1931	1740
	1740	1750
	1392	1800
	1041	1810
	770	1820
	519	1830
	226	1840
	12	1850
	1	1851

Profile	D(m)	GMT
86/1	1	0010
	197	0020
	474	0030
	745	0040
	1004	0050
	1231	0100
	1437	0110
	1657	0120
	1803	0130
	2038	0140
	2185	0149
86/2	2190	0150
	1952	0200
	1670	0210
	1297	0220
	954	0230
	724	0240
	456	0250
	178	0300
	1	0309
86/3	1	0319
	36	0320
	167	0330
	304	0340
	387	0350
	754	0400
	952	0410
	1204	0420
	1493	0430
	1816	0440
	2081	0449
86/4	2069	0454
	1920	0500
	1605	0510
	1271	0520
	1020	0530
	752	0540
	487	0550
	132	0600
	9	0610
87/1	1	1225
	64	1230
	272	1240
	538	1250
	836	1300

Profile	D(m)	GMT
87/1	1171	1310
	1455	1320
	1768	1330
	2069	1340
87/2	2037	1345
	1920	1350
	1663	1400
	1360	1410
	1021	1420
	641	1430
	257	1440
	17	1450
88/1	1	2136
	66	2140
	412	2150
	453	2151
88/2	2	2310
	192	2320
	549	2330
	883	2340
	1302	2350
	1660	2400
	1877	0010
	2110	0020
	2134	0021
88/3	2137	0023
	1888	0030
	1570	0040
	1283	0050
	1081	0100
	862	0110
	614	0120
	369	0130
	183	0140
	1	0150
88/4	1	0150
	134	0200
	389	0210
	729	0220
	1021	0230
	1185	0240
	1370	0250
	1596	0300
	1855	0310
	2131	0319

APPENDIX (Cont.)
Timing of Profiles

Profile	D(m)	GMT
88/5	2132	0321
	1843	0330
	1595	0340
	1280	0350
	1041	0400
	817	0410
	584	0420
	416	0430
	146	0440
	23	0450
	1	0451
89/1	1	0915
	208	0920
	550	0930
	984	0940
	1333	0950
	1657	1000
	2129	1010
89/2	2117	1015
	2011	1020
	1834	1030
	1586	1040
	1258	1050
	938	1100
	665	1110
	382	1120
	198	1130
	1	1136
89/3	4	1140
	428	1150
	762	1200
	1006	1210
	1231	1220
	1434	1230
	1597	1240
	1735	1250
	1871	1300
	1992	1310
	2096	1320
	2164	1326
89/4	2149	1326
	2014	1330

Profile	D(m)	GMT
89/1	1651	1340
	1375	1350
	1087	1400
	871	1410
	612	1420
	399	1430
	264	1440
	110	1450
	1	1500
90/1	1	1730
	200	1740
	602	1750
	957	1800
	1320	1810
	1683	1820
	2023	1830
	2052	1831
90/2	2044	1837
	1970	1840
	1688	1850
	1348	1900
	1073	1910
	804	1920
	765	1930
	558	1940
	342	1950
	8	2000
90/3	6	2010
	274	2020
	621	2030
	886	2040
	1098	2050
	1404	2100
	1800	2110
	2080	2120
90/4	2089	2136
	1993	2140
	1752	2150
	1543	2200
	1298	2210
	1000	2220
	633	2230

Profile	D(m)	GMT
90/4	277	2240
	100	2250
	1	2255
91/1	1	0320
	216	0330
	565	0340
	890	0350
	1259	0400
	1556	0410
	2022	0420
91/2	2007	0450
	1775	0500
	1685	0510
	1150	0520
	1008	0530
	576	0540
	34	0550
	1	0552
92/1	1	1100
	197	1110
	406	1120
	668	1130
	910	1140
	1157	1150
	1380	1200
	1605	1210
	2072	1220
92/2	2061	1226
	1976	1230
	1676	1240
	1347	1250
	1025	1300
	714	1310
	516	1320
	173	1330
	1	1338
109/1	1	1223
	175	1230
	595	1240

Profile	D(m)	GMT
109/1	1089	1250
	1346	1300
	1933	1310
	1983	1312
109/2	2054	1327
	2021	1330
	2021	1340
	1984	1350
	1592	1400
	1159	1410
	720	1420
	291	1430
	1	1438
110/1	2	1201
	419	1210
	971	1220
	1703	1230
	2048	1235
110/2	2052	1238
	2004	1240
	1737	1250
	1336	1300
	863	1310
	306	1320
	1	1326
111/1	5	2329
	27	2330
	376	2340
	708	2350
	1029	2400
	1452	0010
	1944	0020
	2071	0022
111/2	2068	0026
	1971	0030
	1644	0040
	1317	0050
	971	0100
	619	0110
	238	0120
	1	0128

APPENDIX (Cont.)
Timing of Profiles

Profile	D(m)	GMT	Profile	D(m)	GMT	Profile	D(m)	GMT	Profile	D(m)	GMT
111/3	3	0130	112/4	797	1310	114/1	778	0120	114/6	1	0721
	424	0140		483	1320		1114	0130			
	778	0150		195	1330		1471	0140			
	1102	0200		1	1337		1816	0150	115/1	6	1218
	1436	0210					2041	0200		73	1220
	1773	0220					2070	0201		407	1230
	2068	0228	113/1	4	1522	114/2	2071	0205		748	1240
111/4	2064	0232		317	1530		1967	0210		1074	1250
	1781	0240		724	1540		1686	0220		1392	1300
	1376	0250		1048	1550		1388	0230		1771	1310
	988	0300		1397	1600		1095	0240		2071	1315
	645	0310		1781	1610		817	0250	115/2	2059	1323
	326	0320		2068	1617		509	0300		1850	1330
	34	0330	113/2	2057	1621		243	0310		1492	1340
	1	0332		1761	1630		1	0320		1148	1350
				1339	1640	114/3	4	0323		764	1400
				1127	1650		171	0330		373	1410
112/1	2	0851		934	1700		434	0340		1	1420
	246	0900		718	1710		678	0350	115/3	3	1424
	588	0910		461	1720		958	0400		171	1430
	896	0920		258	1730		1279	0410		499	1440
	1190	0930		15	1740		1625	0420		842	1450
	1437	0940		1	1741		2008	0430		1182	1500
	1659	0950	113/3	1	1746		2074	0431		1508	1510
	1900	1000		87	1750	114/4	2078	0434		1883	1520
	2068	1007		408	1800		1908	0440		2071	1524
112/2	2034	1011		639	1810		1634	0450	115/4	2069	1528
	1735	1020		783	1820		1316	0500		2000	1530
	1474	1030		963	1830		948	0510		1615	1540
	1243	1040		1163	1840		565	0520		1509	1550
	1017	1050		1545	1850		292	0530		1102	1600
	724	1100		1939	1900		1	0534		760	1610
	415	1110		2069	1903	114/5	2	0541		430	1620
	79	1120	113/4	2066	1905		247	0550		86	1630
	1	1122		1946	1910		506	0600		1	1633
112/3	4	1130		1538	1920		747	0610			
	395	1140		1114	1930		1054	0620	116/1	3	2044
	819	1150		876	1940		1488	0630		183	2050
	1228	1200		615	1950		1554	0631		589	2100
	1594	1210		322	2000	114/6	1563	0634		250	2110
	1901	1220		1	2009		1416	0640		1	2115
	2068	1226					1008	0650	116/2	1	0028
112/4	2050	1231					567	0700		43	0030
	1769	1240	114/1	4	0054		270	0710		392	0040
	1450	1250		200	0100		18	0720			
	1123	1300		498	0110						

APPENDIX (Cont.)
Timing of Profiles

Profile	D(m)	GMT
116/2	746	0050
	1104	0100
	1426	0110
	1723	0120
	1996	0130
	2069	0133
116/3	2053	0136
	1924	0140
	1554	0150
	1202	0200
	866	0210
	480	0220
	76	0230
	1	0232
116/4	4	0237
	80	0240
	449	0250
	849	0300
	1237	0310
	1583	0320
	1894	0330
	2070	0336
116/5	2060	0338
	2008	0340
	1679	0350
	1366	0400
	1062	0410
	689	0420
	378	0430
	60	0440
	1	0447
117/1	3	0926
	143	0930
	488	0940
	758	0950
	910	1000
	1156	1010
	1419	1020
	1650	1030
	1874	1040
	2038	1046

Profile	D(m)	GMT
117/2	2014	1056
	1935	1100
	1710	1110
	1438	1120
	1144	1130
	839	1140
	474	1150
	73	1200
	1	1202
117/3	2	1209
	19	1210
	369	1220
	764	1230
	1124	1240
	1456	1250
	1752	1300
	2044	1310
	2071	1311
117/4	2074	1313
	1844	1320
	1515	1330
	1129	1340
	738	1350
	378	1400
	18	1410
	1	1411
119/1	5	1352
	427	1400
	947	1410
	1470	1420
119/2	1471	1430
	1156	1440
	742	1450
	416	1500
	21	1510
	1	1512

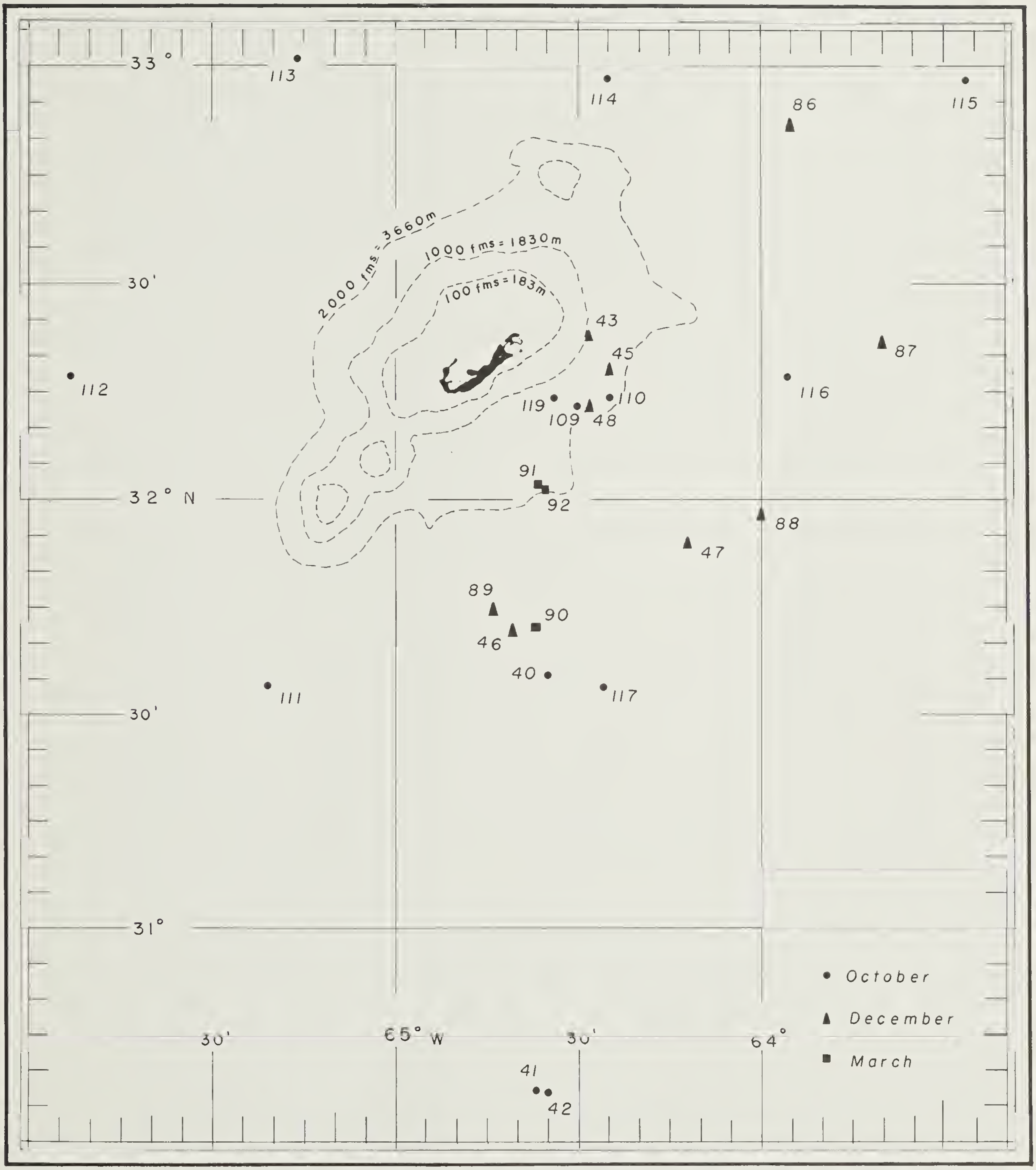


Fig. I *Chart of Stations*

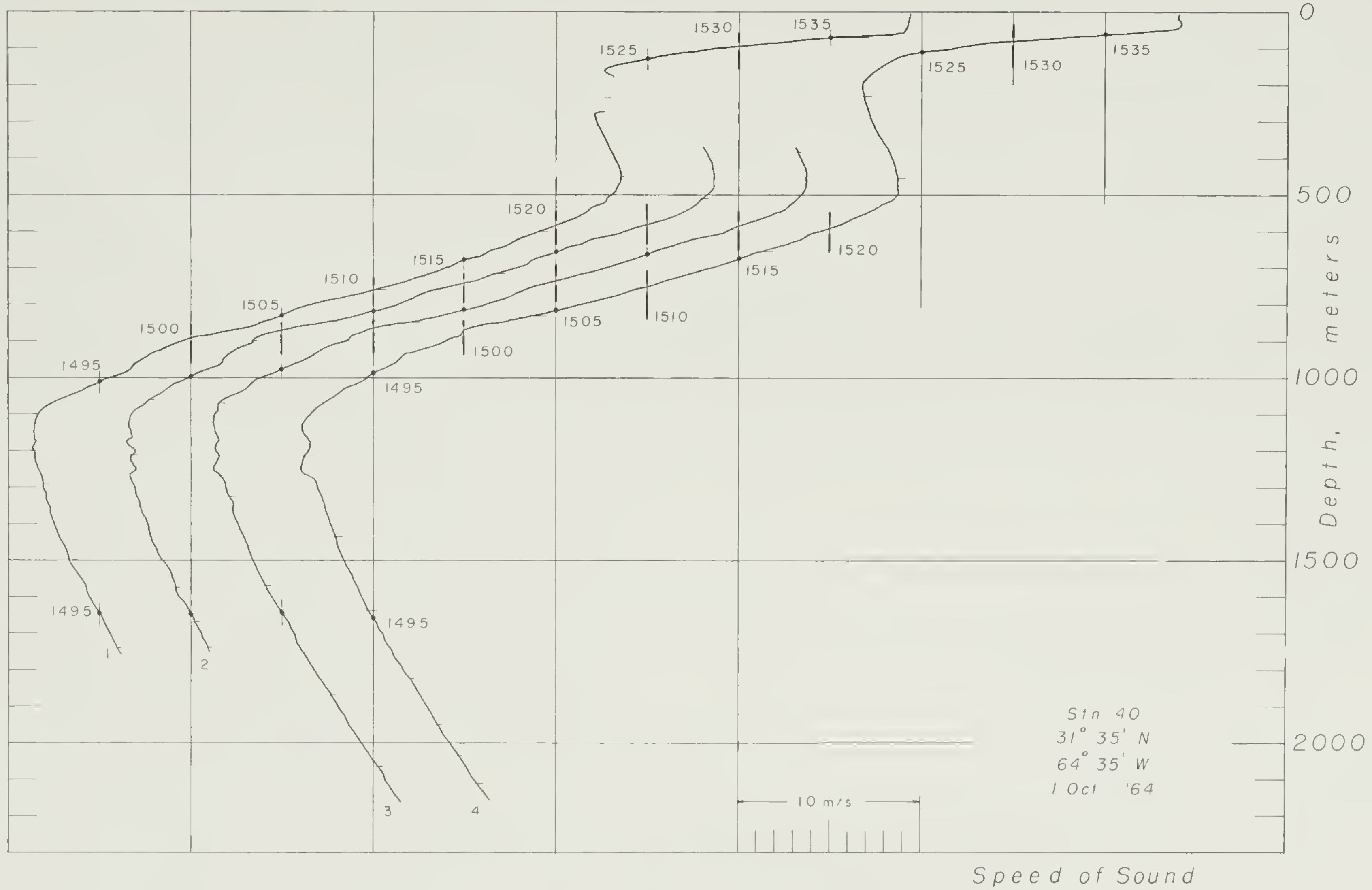


Fig. 2 Sound Speeds — Station 40

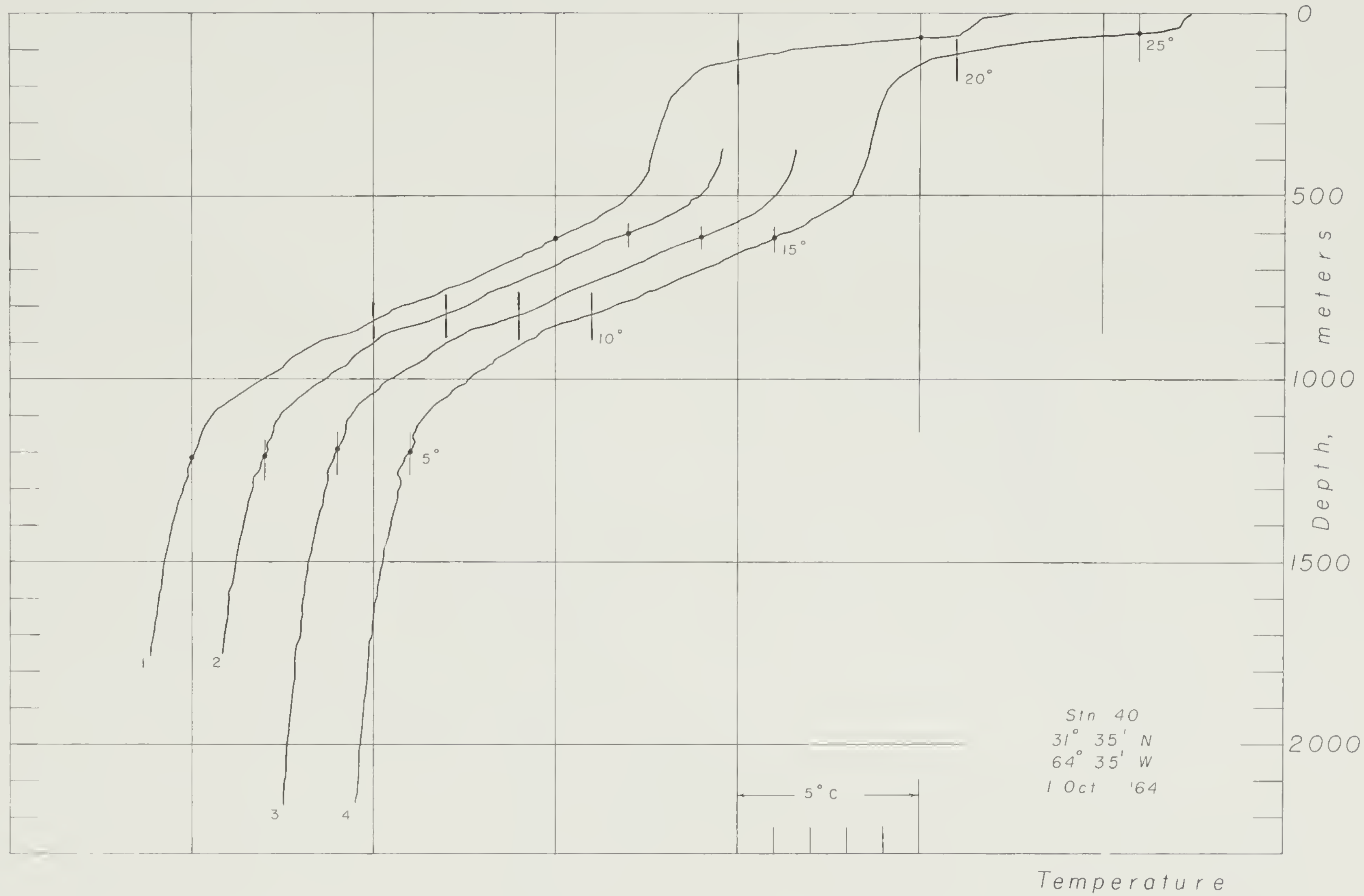


Fig. 3 *Temperatures — Station 40*

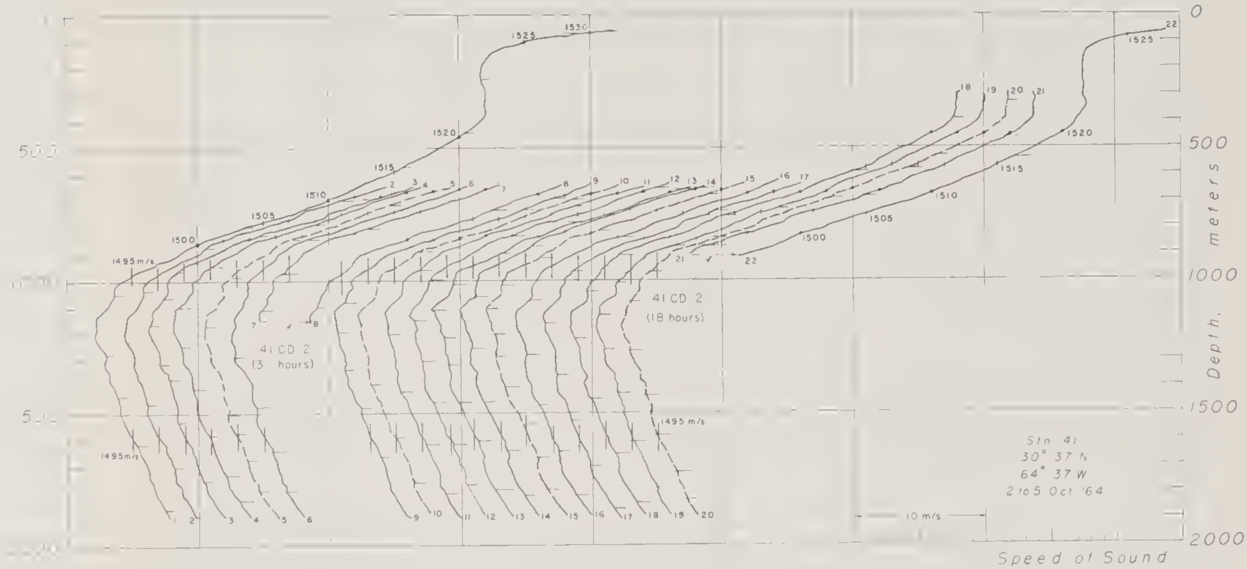


Fig. 4 *Sound Speeds* — Station 41

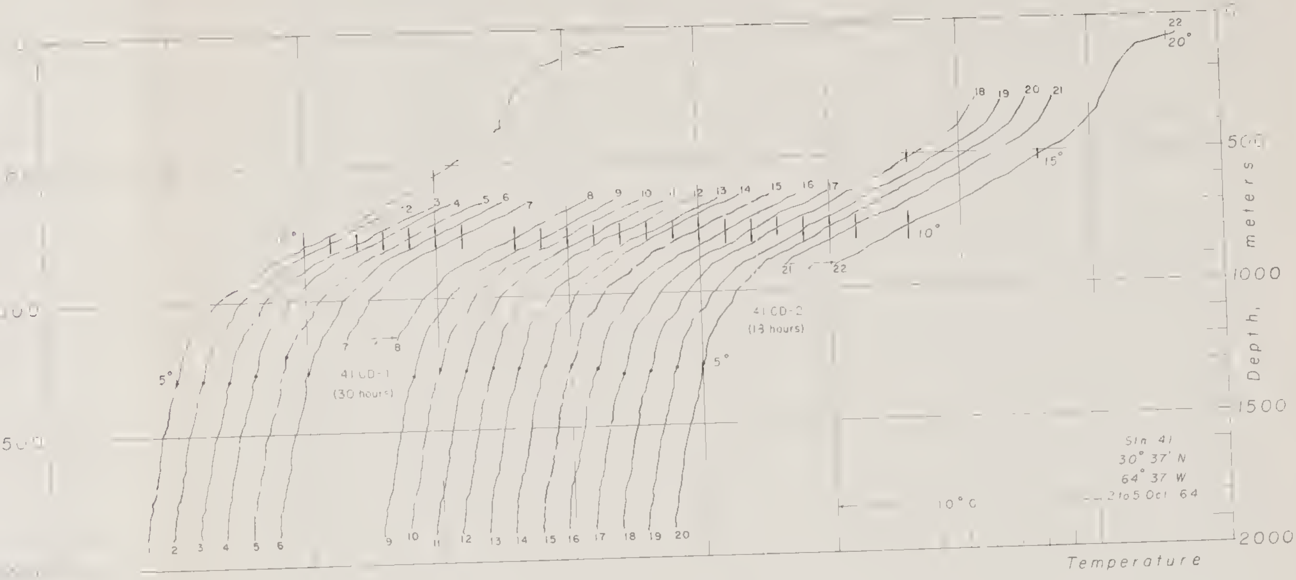


Fig. 5 *Temperatures* — Station 41

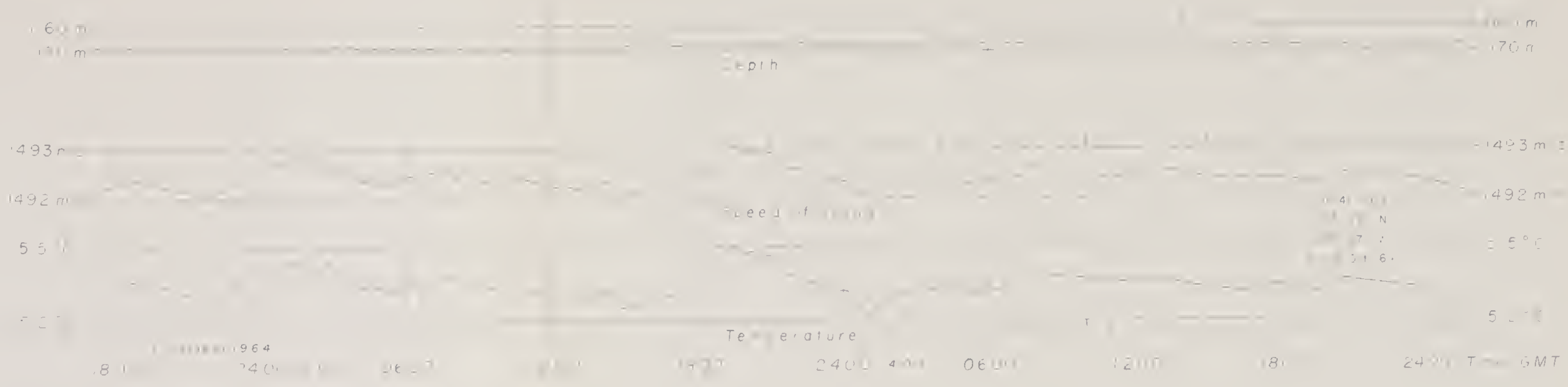


Fig. 6 *Constant Depth Time Series, 41 CD 1.*
Sound Speed and Temperature at 1170 m, below the Main Thermocline

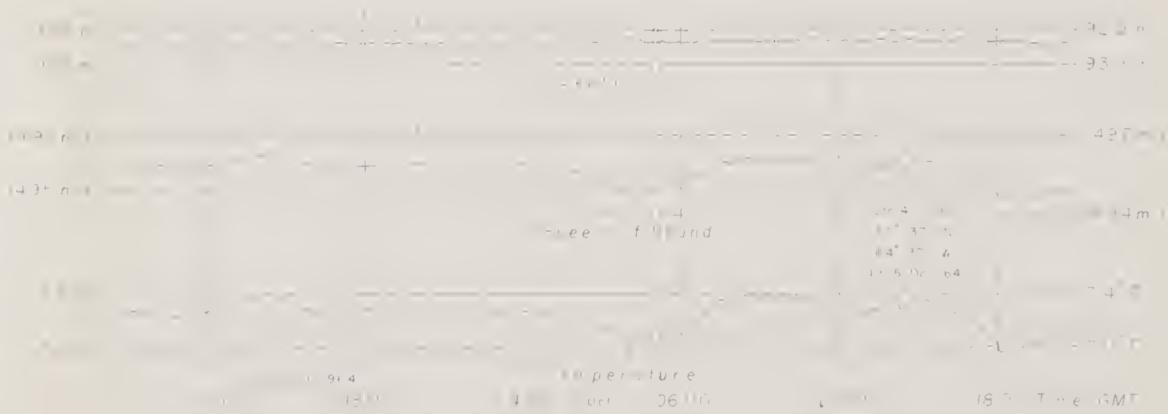


Fig. 7 *Constant Depth Time Series, 41 CD 2.*
Sound Speed and Temperature at 920 m, in the Main Thermocline

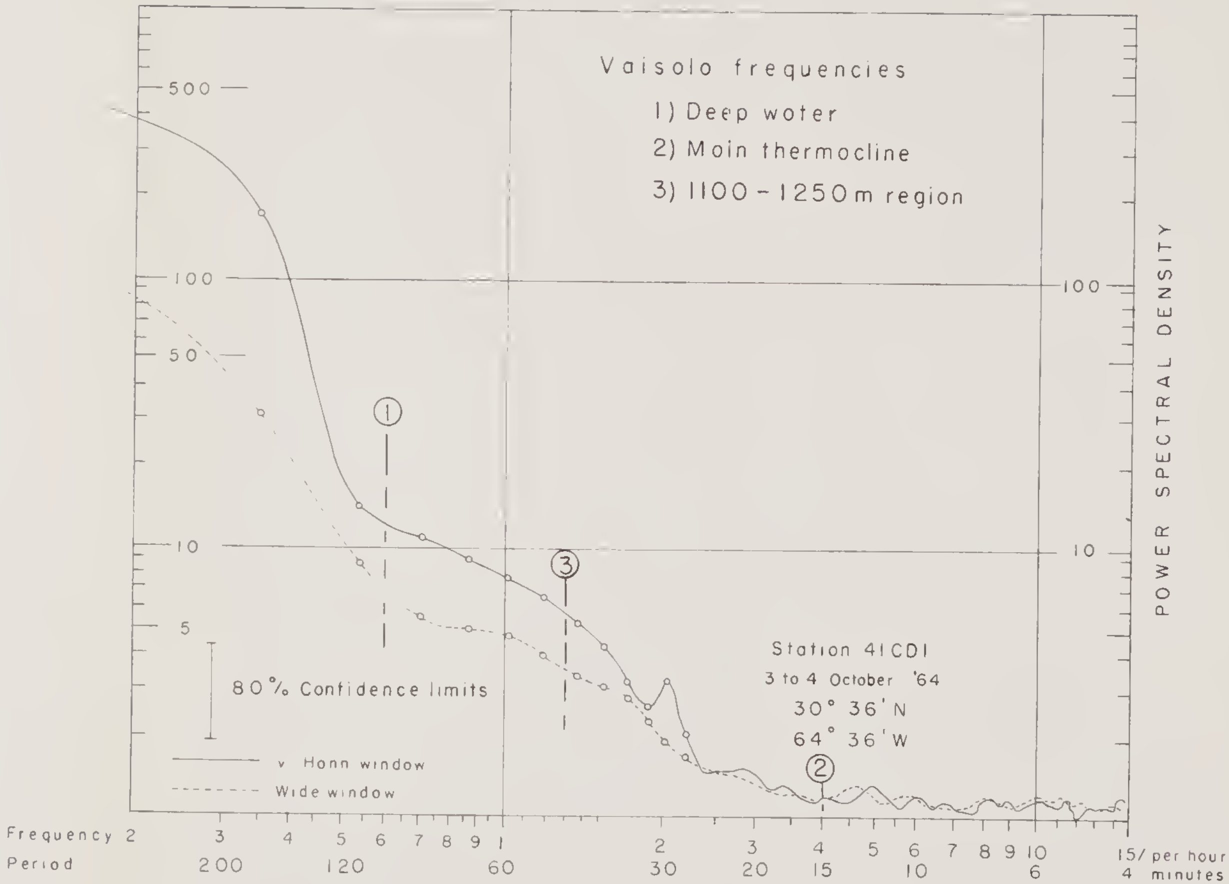


Fig. 8 POWER DENSITY SPECTRUM of 30 hour constont depth recording at 1170 meters
(Below moin Thermocline)

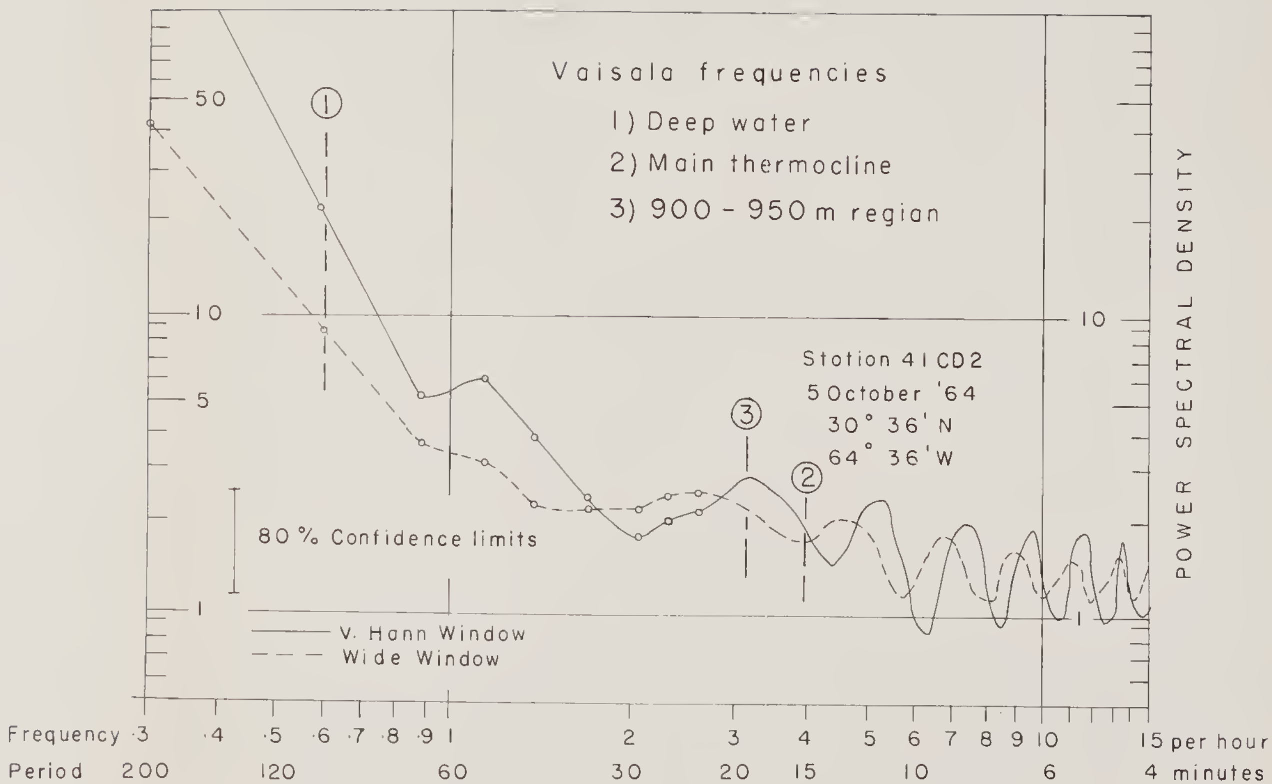


Fig. 9 POWER DENSITY SPECTRUM of 18 hour constant depth recording at 920 meters
(In main Thermocline)

Fig. 10 *Sound Speeds* — Station 42

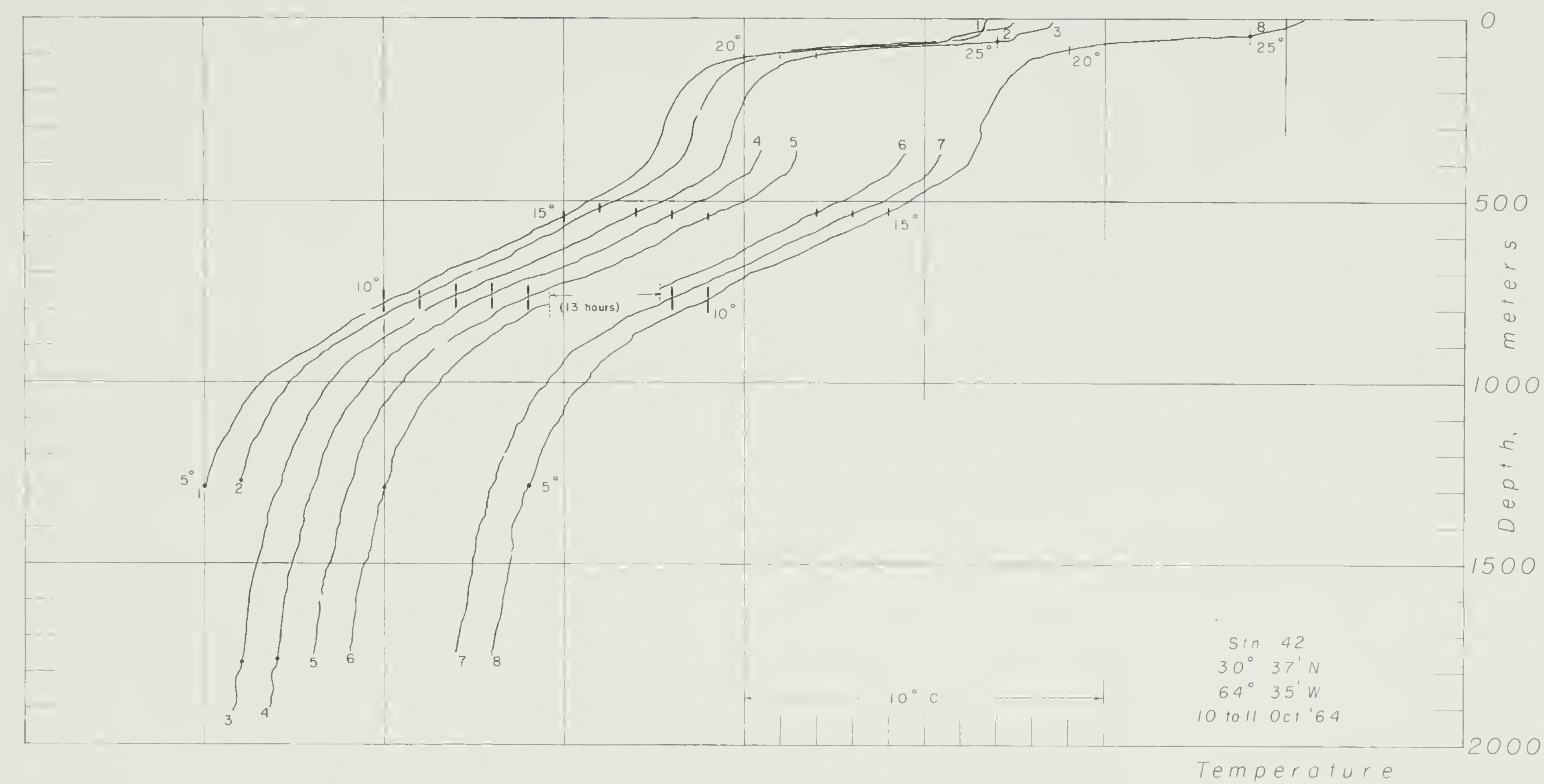


Fig. 11 *Temperatures* — Station 42

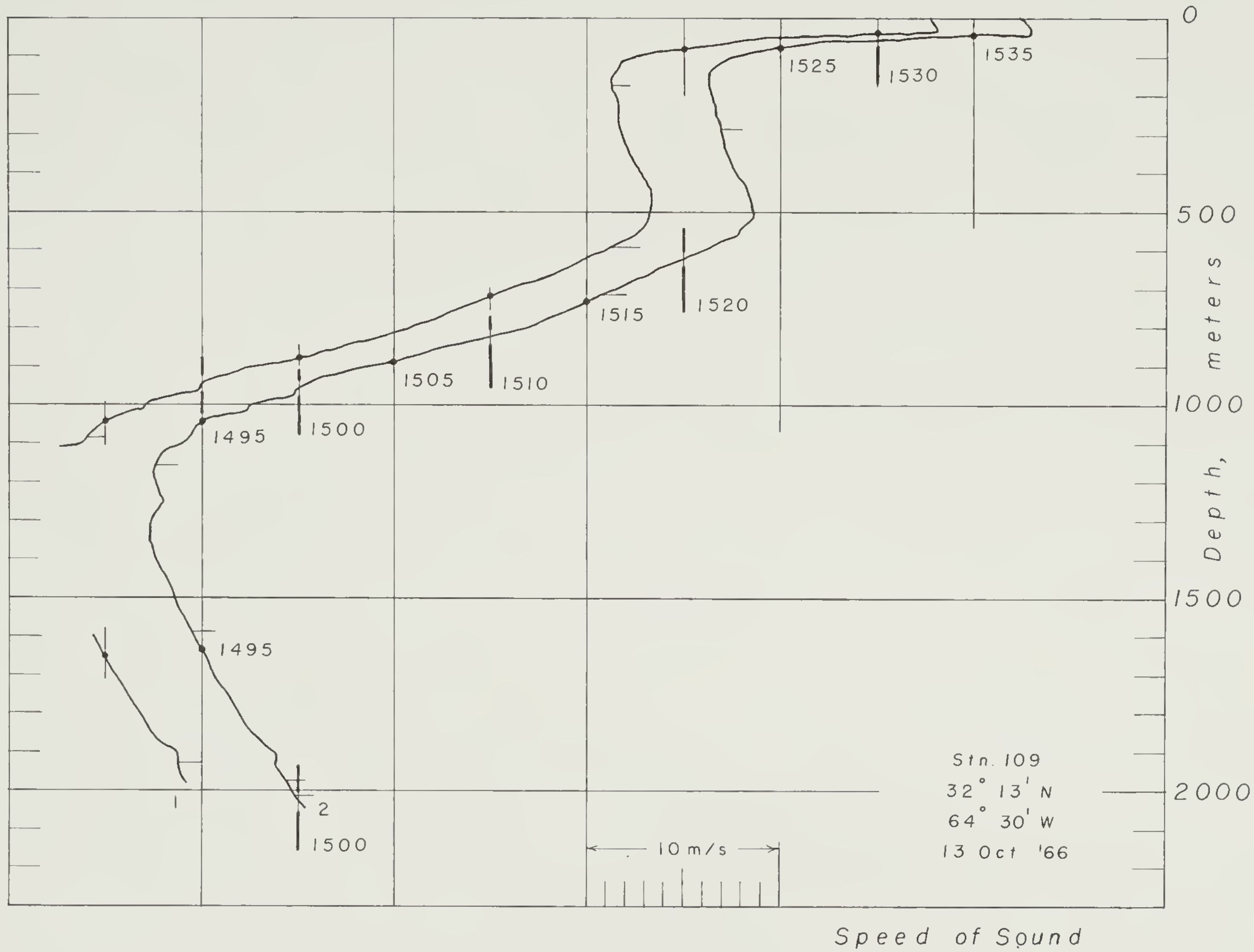


Fig. 12 *Sound Speeds – Station 109*

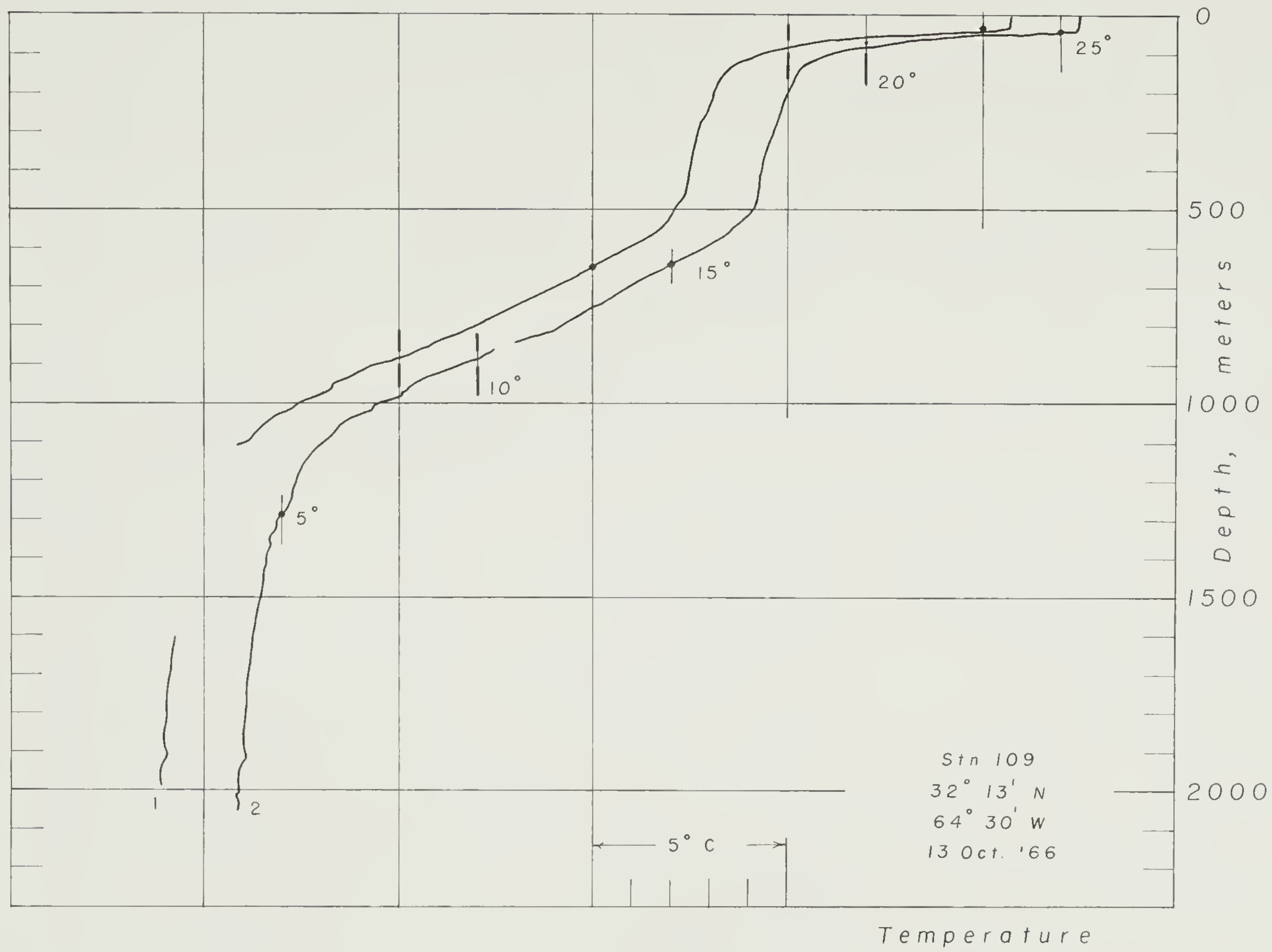


Fig. 13 *Temperatures* – Station 109

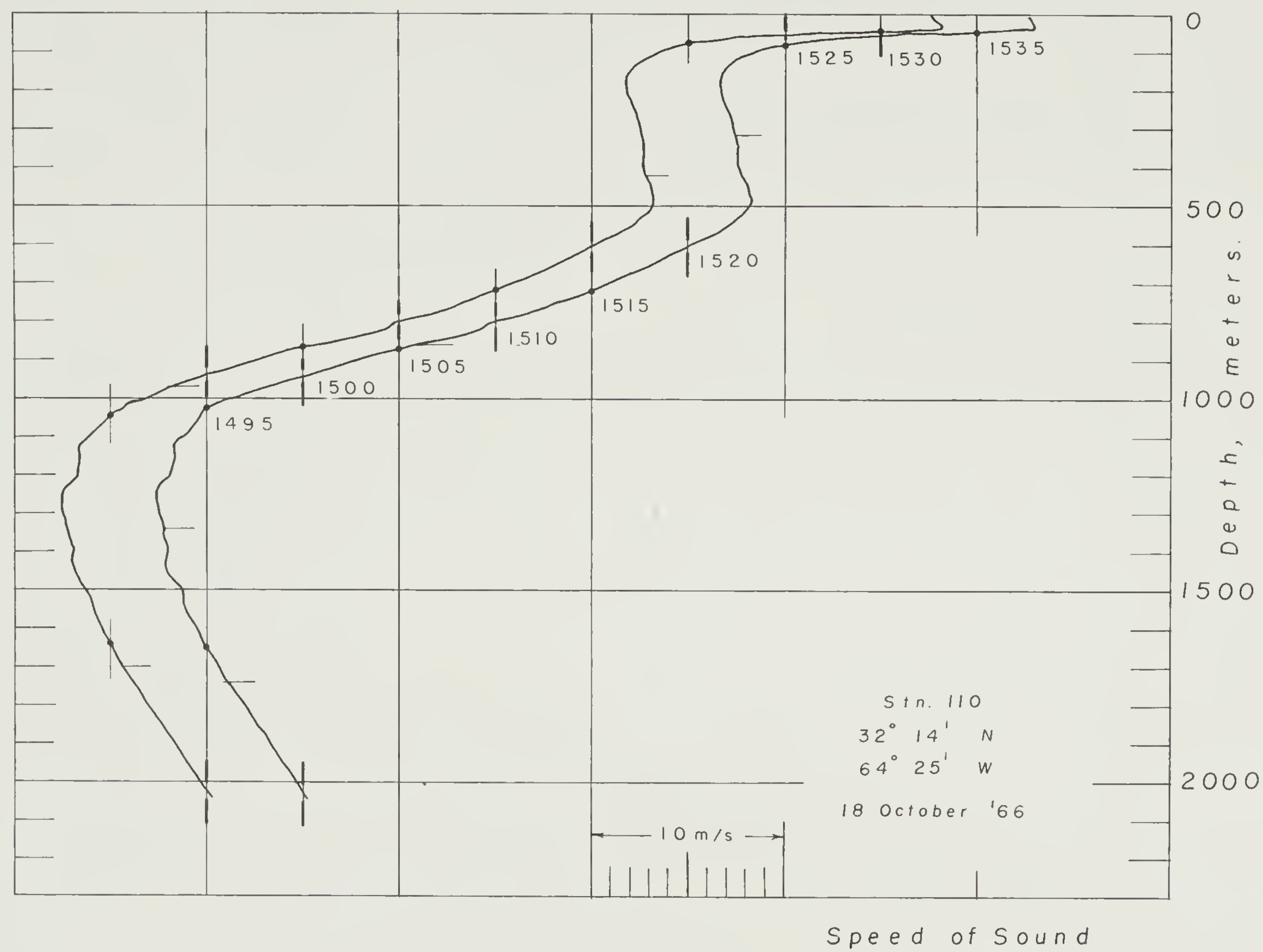


Fig. 14 *Sound Speeds* – Station 110

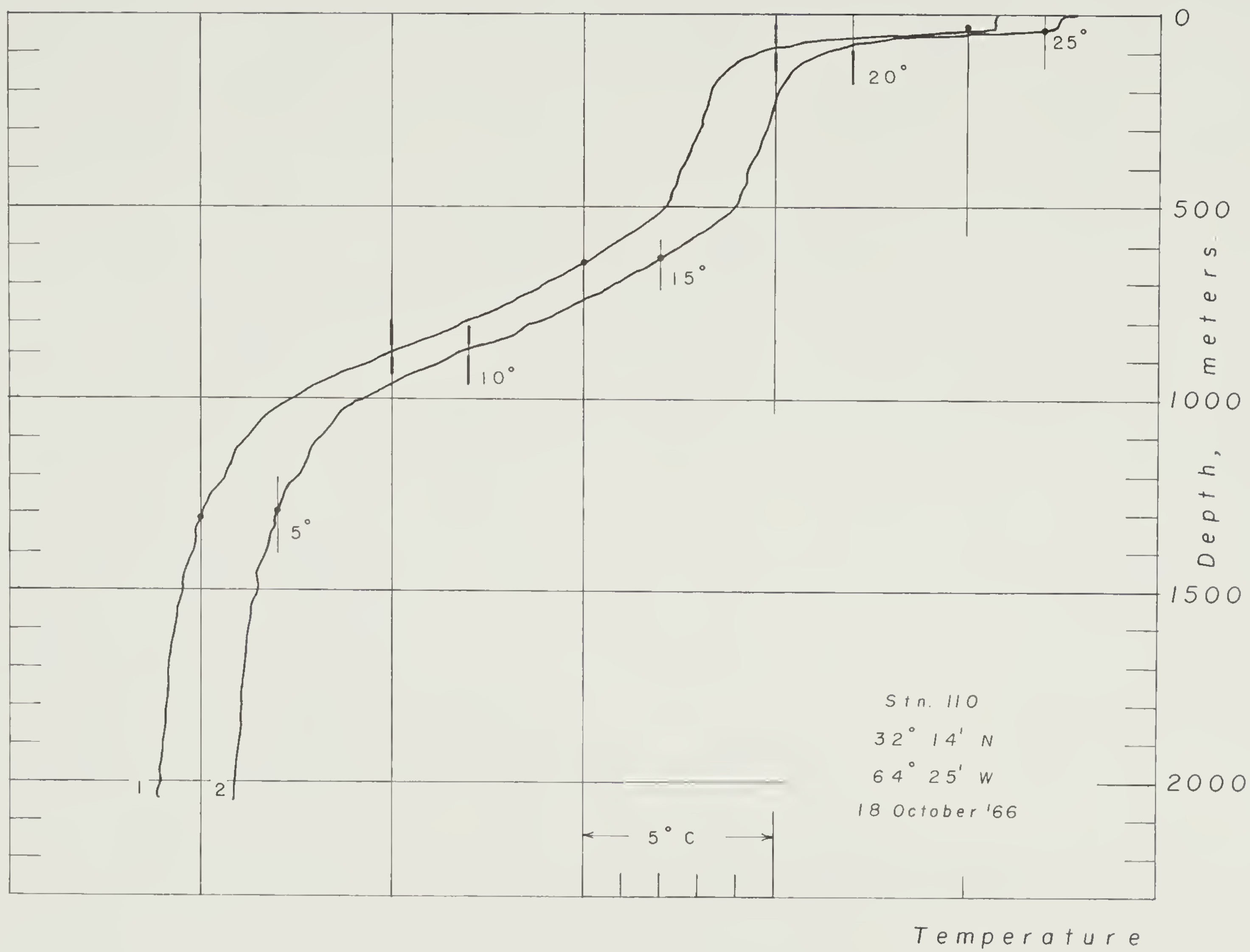


Fig. 15 *Temperatures* — Station 110

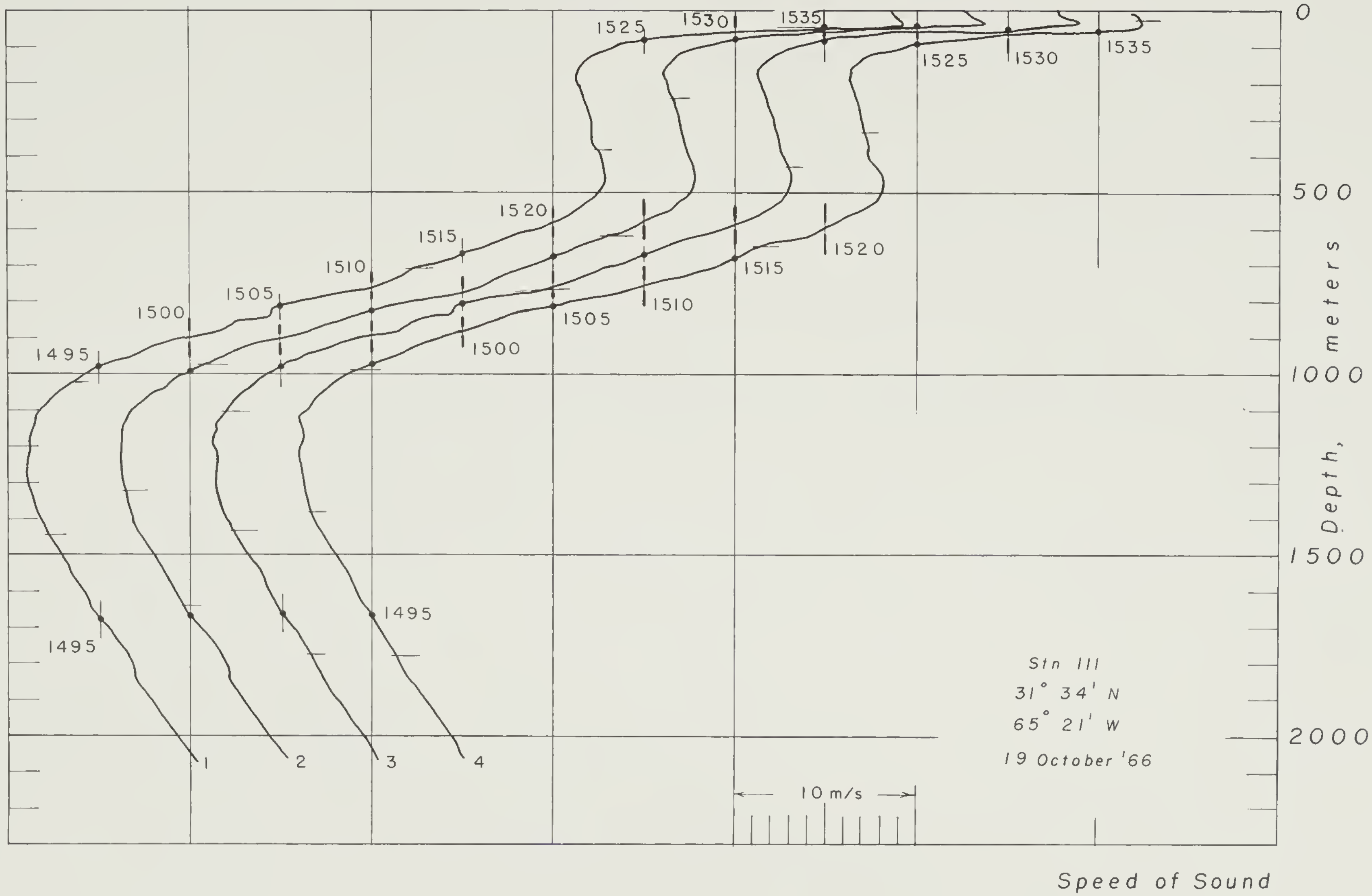


Fig. 16 *Sound Speeds – Station III*

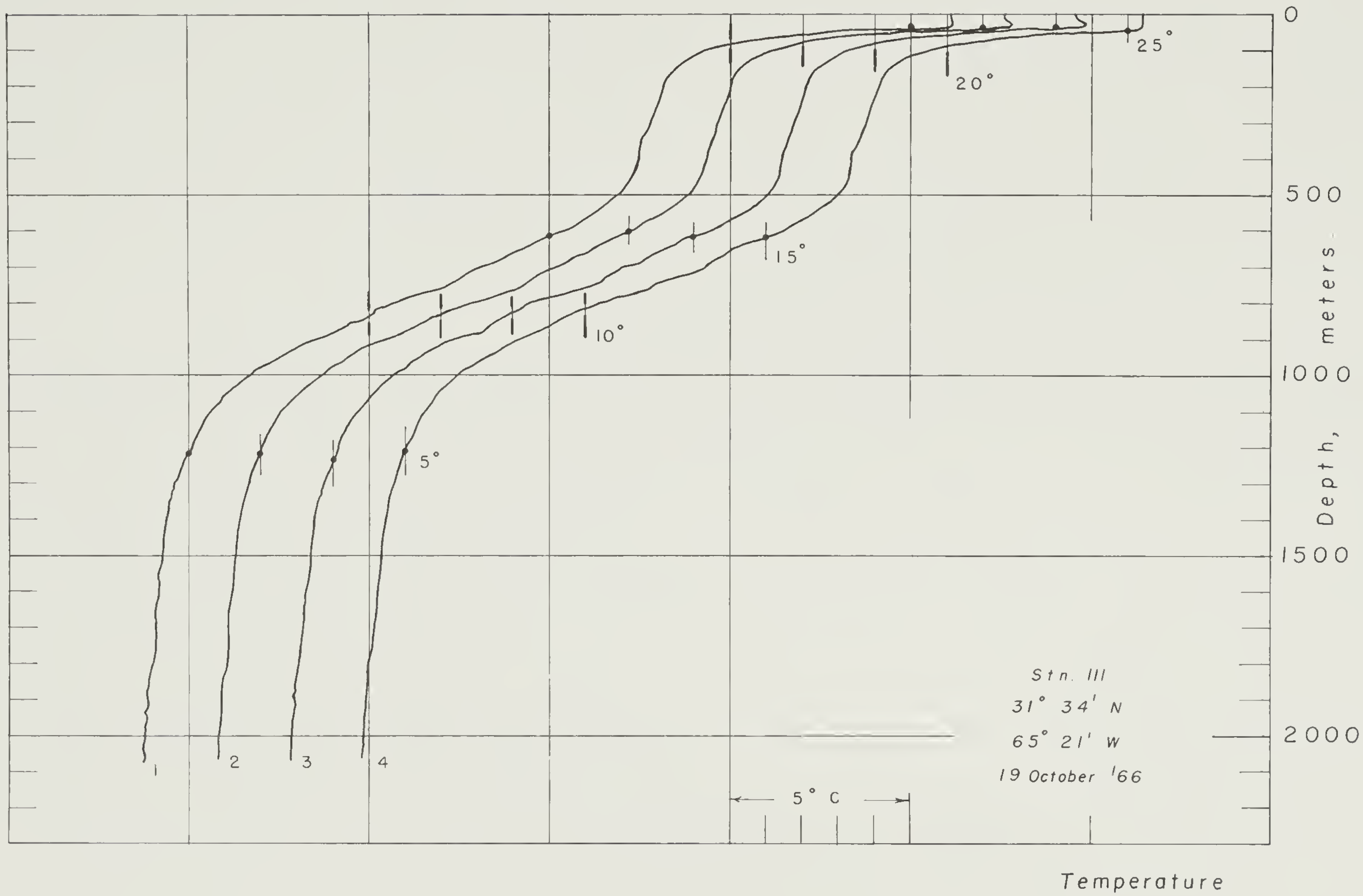


Fig. 17 *Temperatures* – Station III

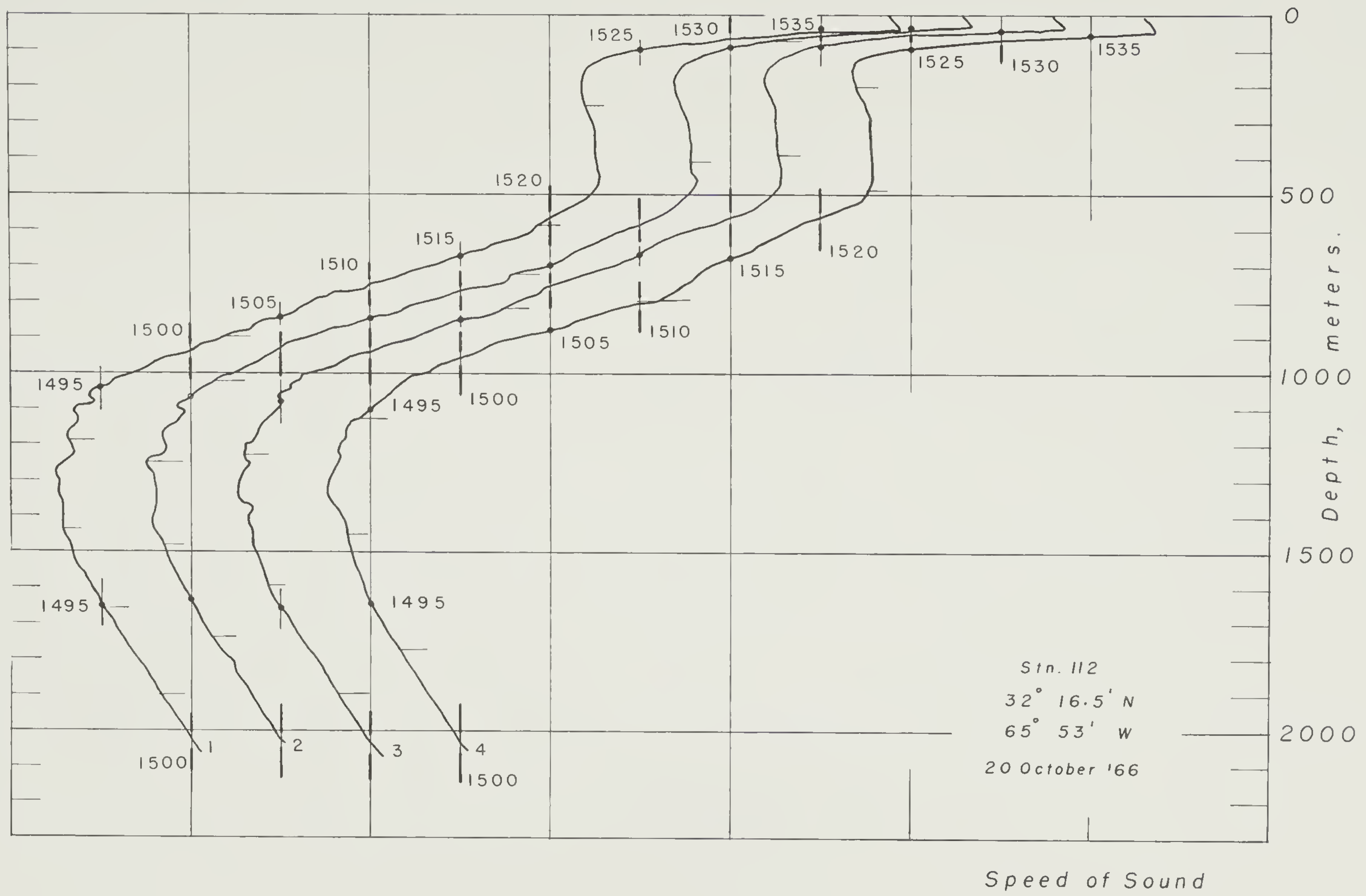


Fig. 18 *Sound Speeds* — Station 112

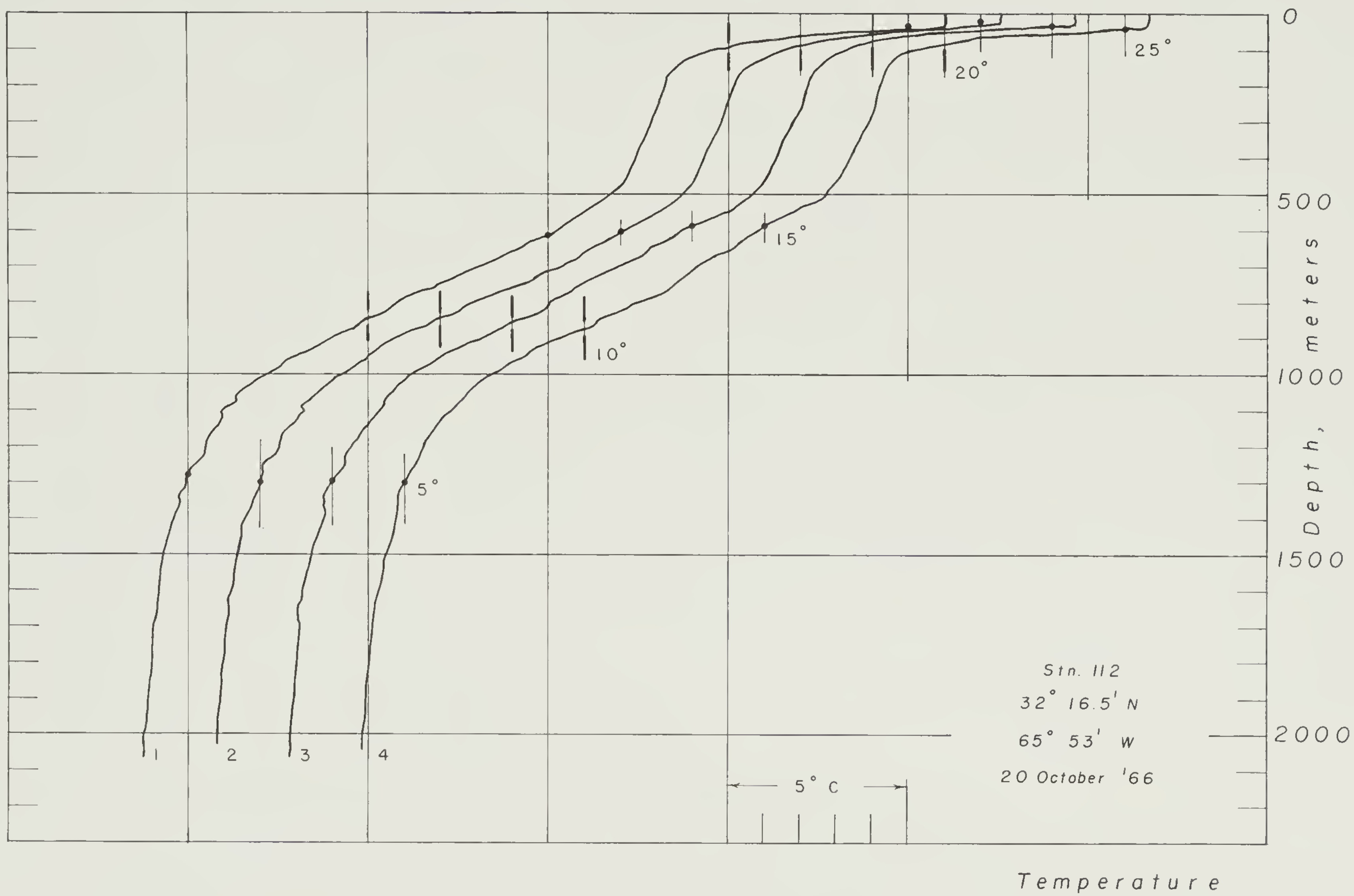


Fig. 19 Temperatures — Station 112

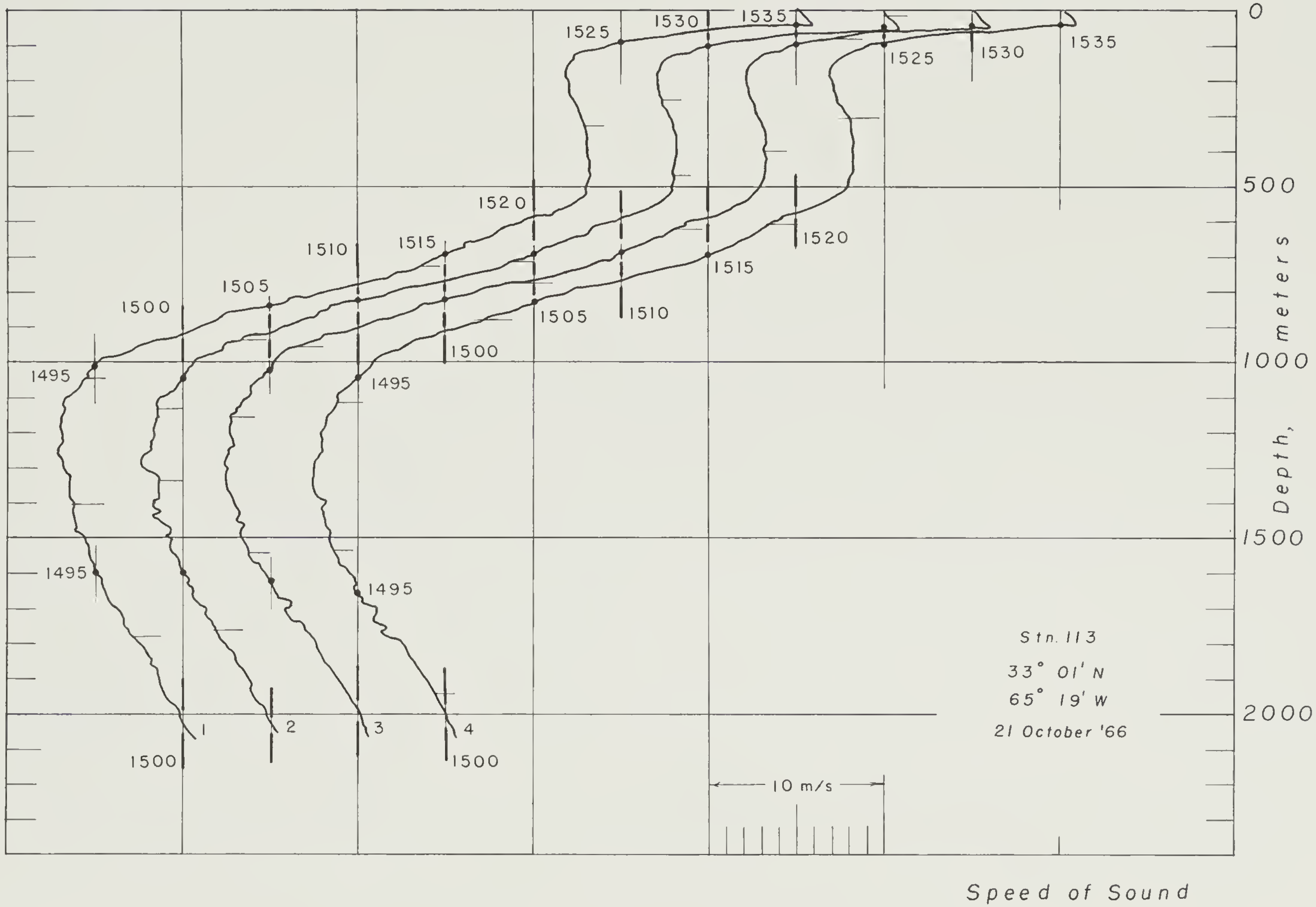


Fig. 20 Sound Speeds — Station 113

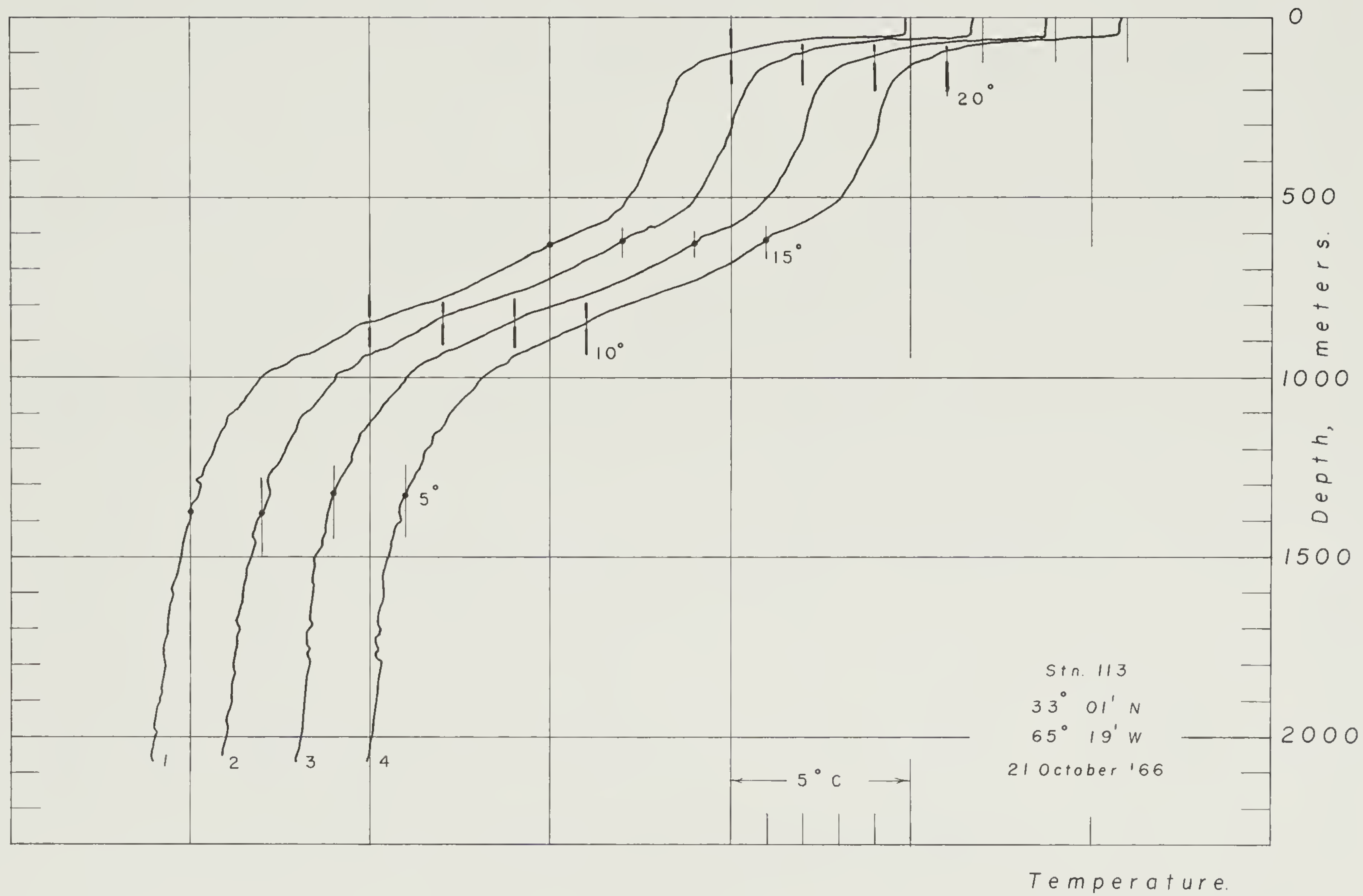


Fig. 21 *Temperatures* — Station 113

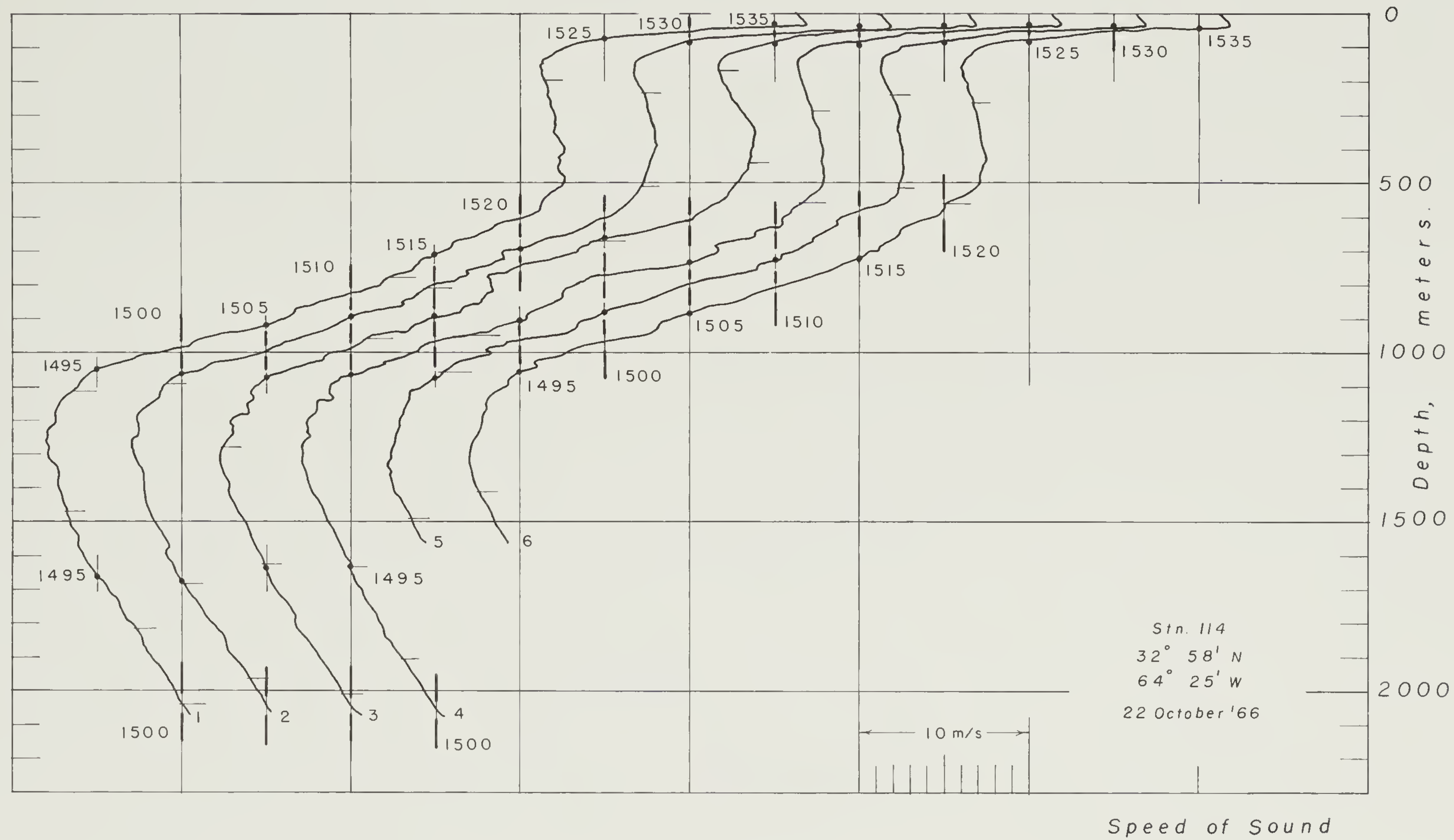


Fig. 22 *Sound Speeds* — Station 114

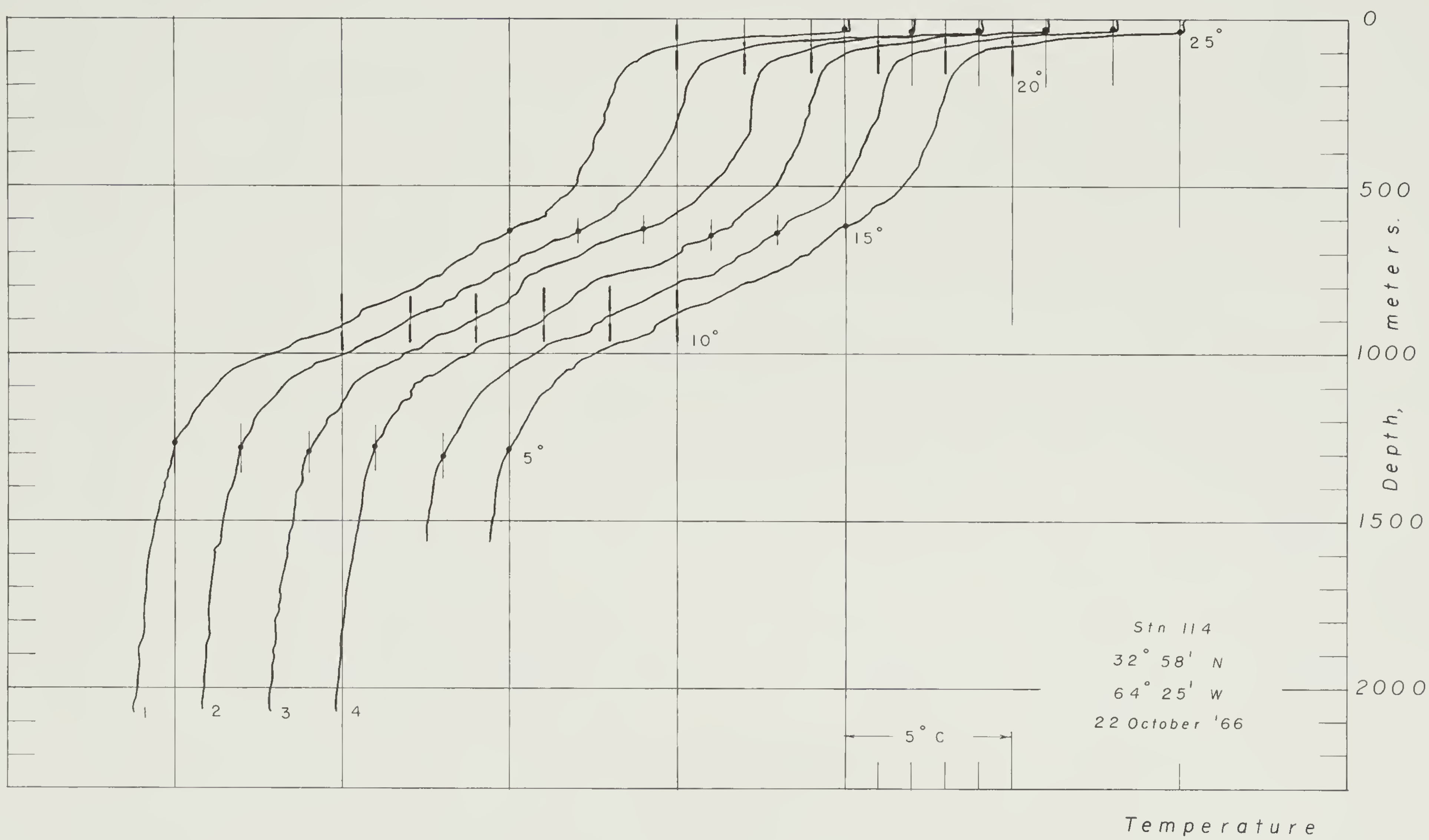


Fig. 23 Temperatures — Station 114

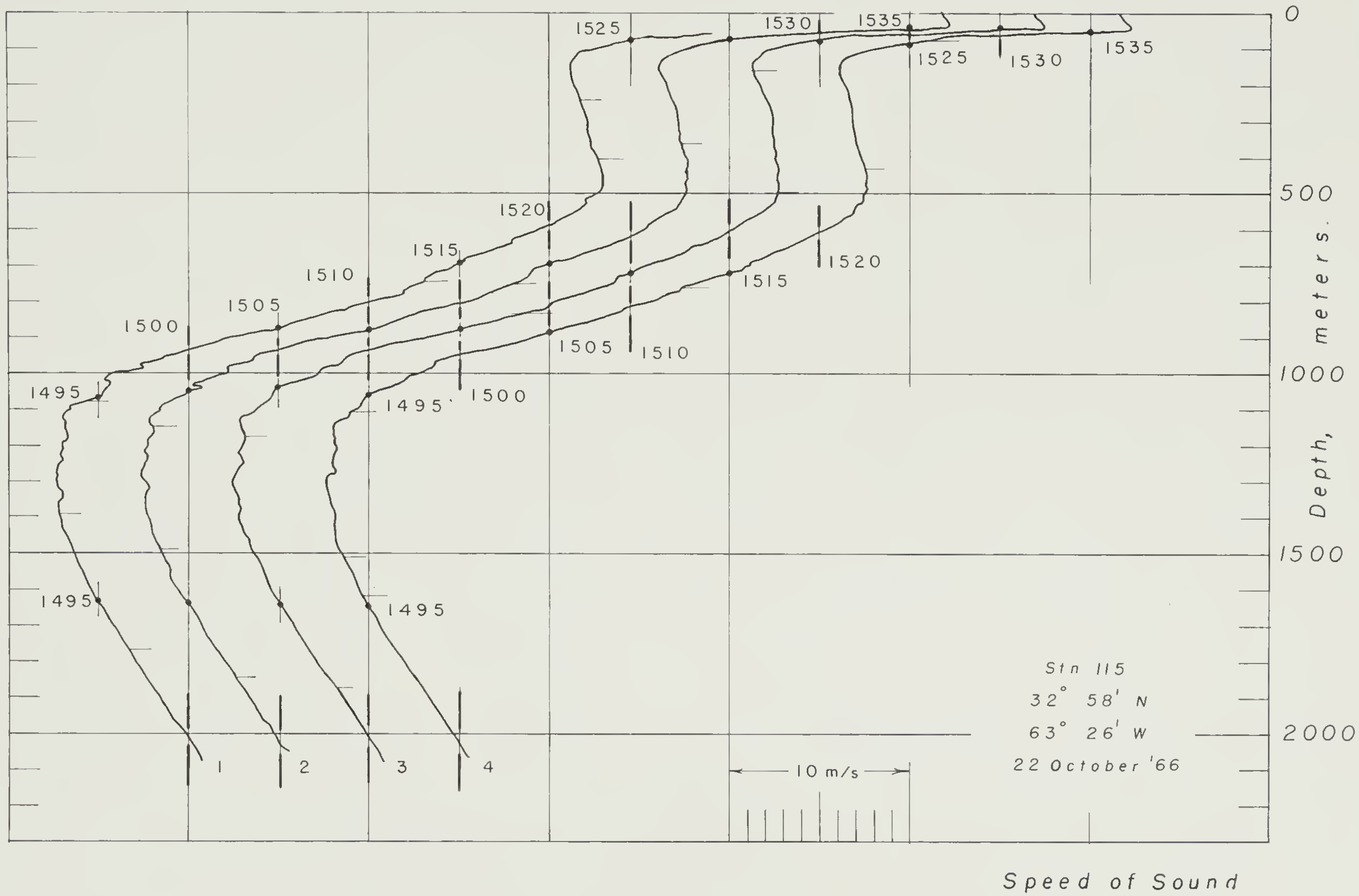


Fig. 24 *Sound Speeds* — Station 115

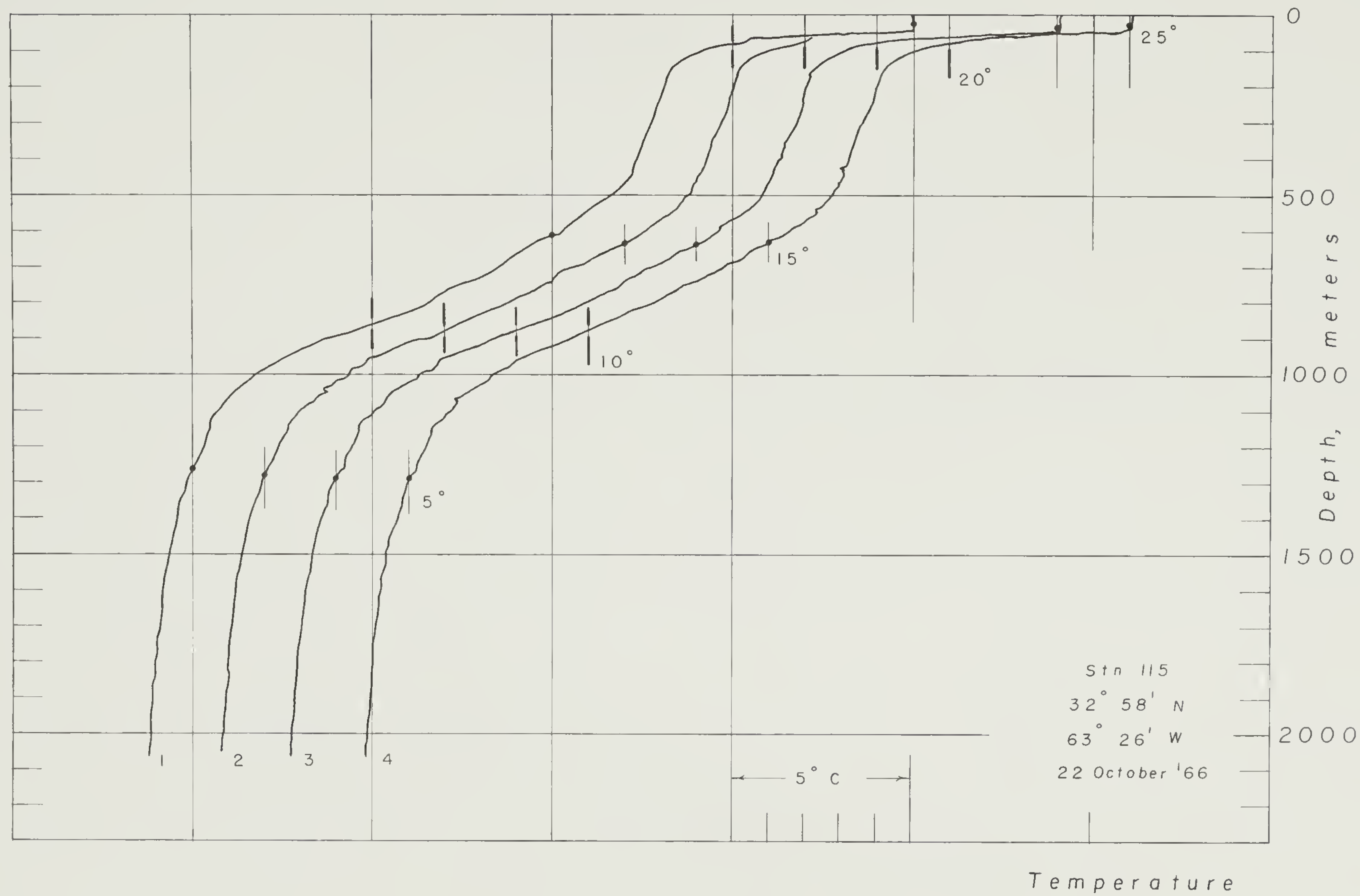


Fig. 25 *Temperatures* — Station 115

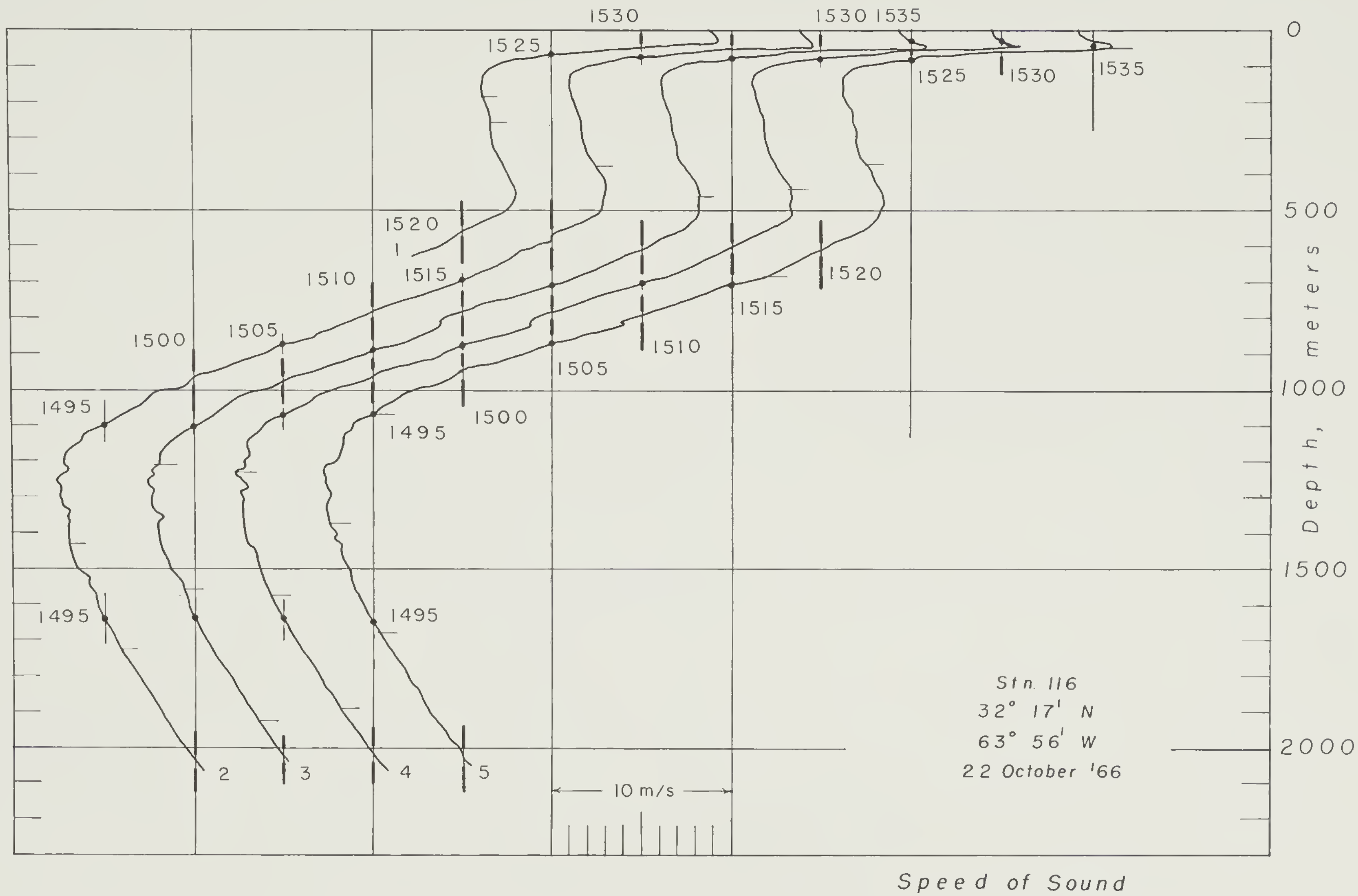


Fig. 26 *Sound Speeds* — Station 116

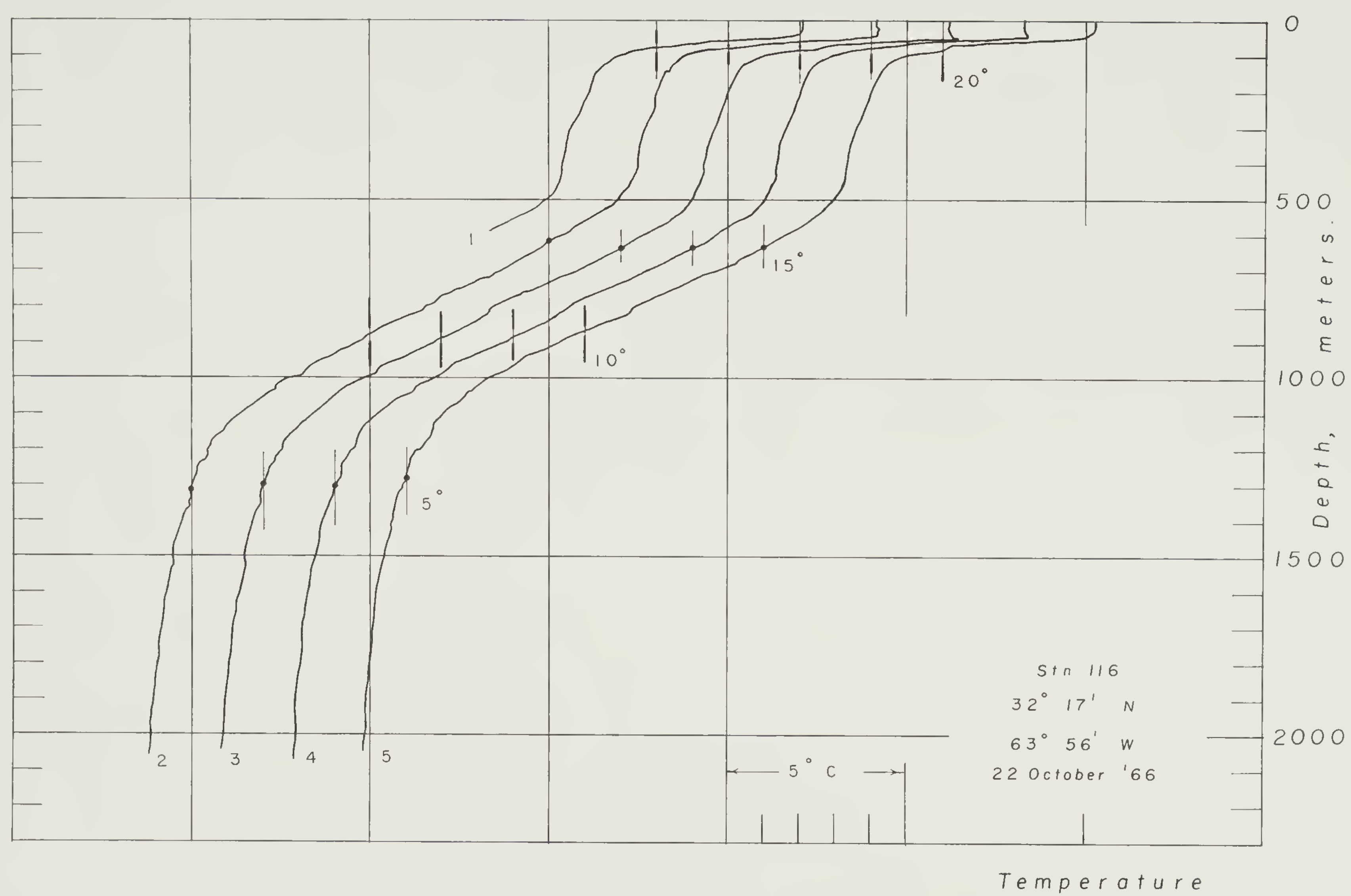


Fig. 27 *Temperatures* — Station 116

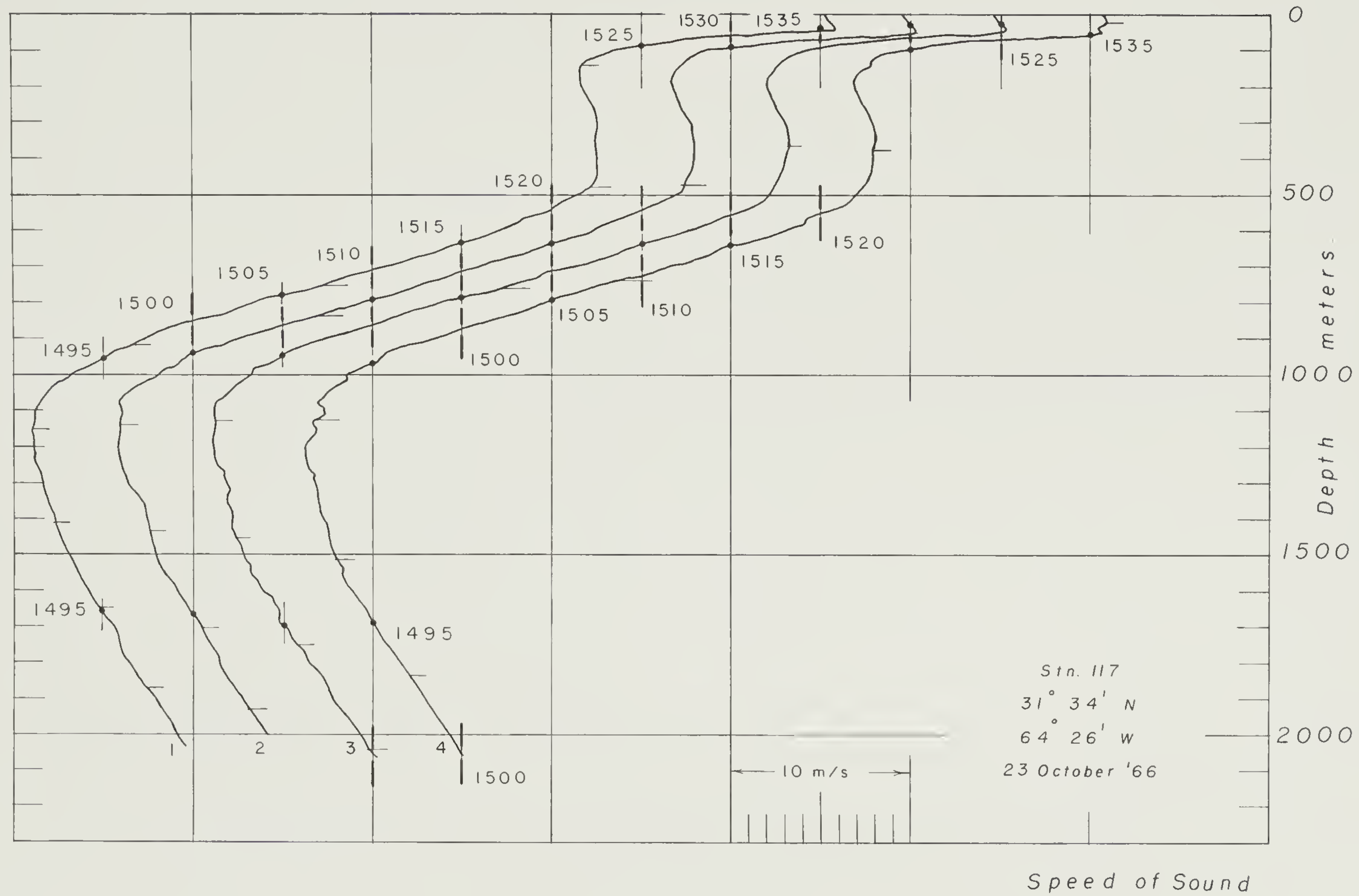


Fig. 28 *Sound Speeds – Station 117*

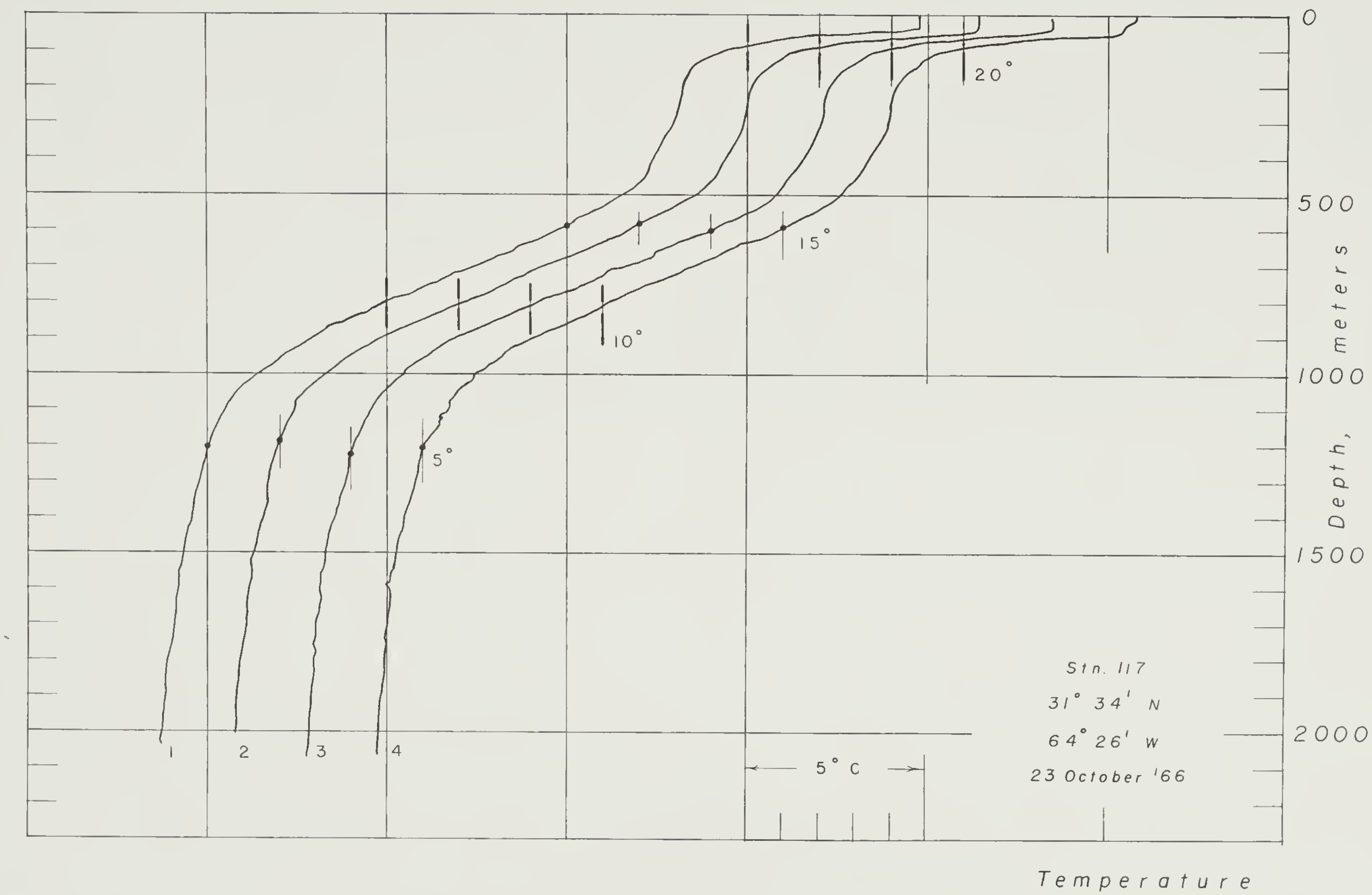


Fig. 29 *Temperatures* — Station 117

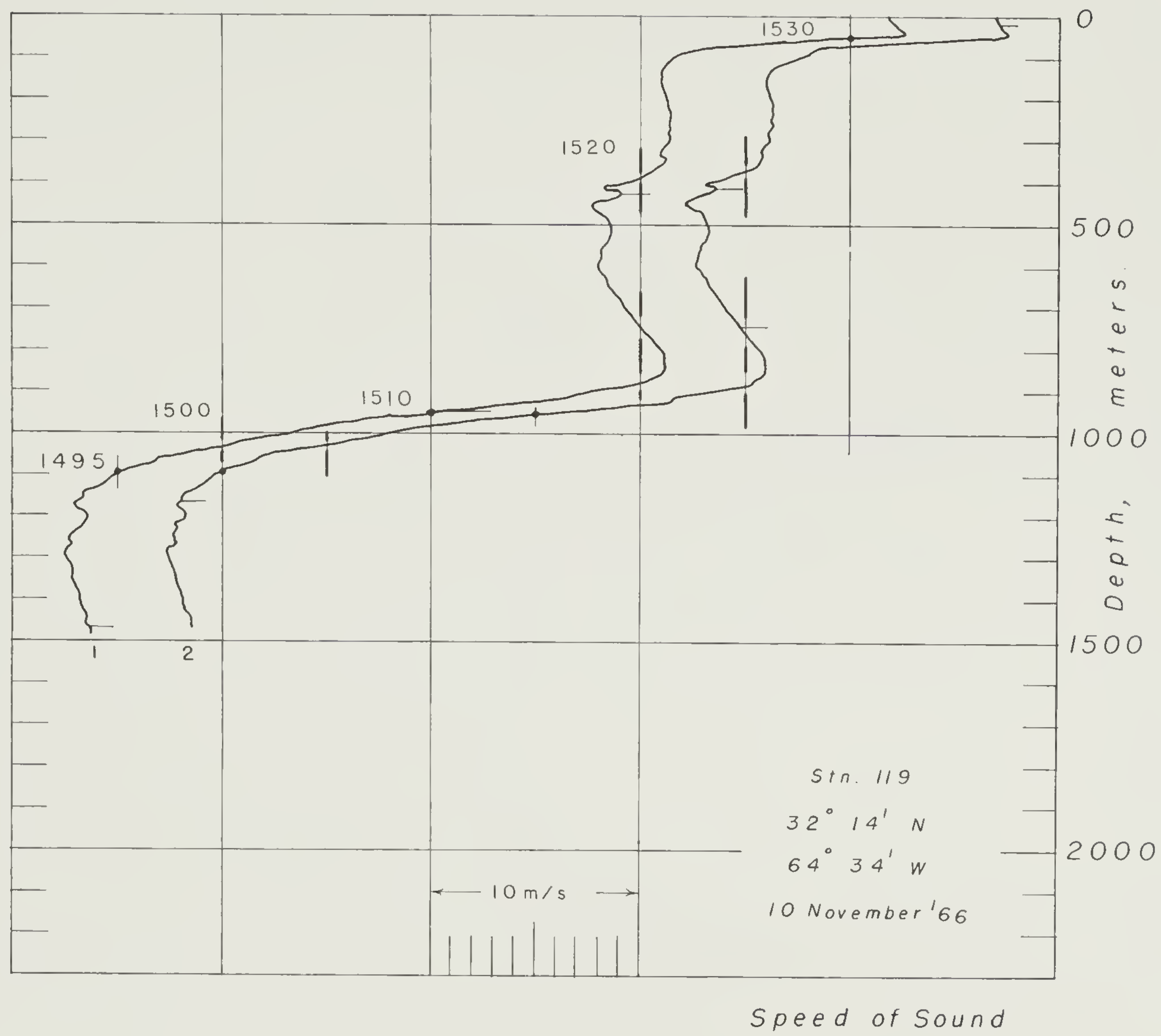


Fig. 30 *Sound Speeds* – Station 119

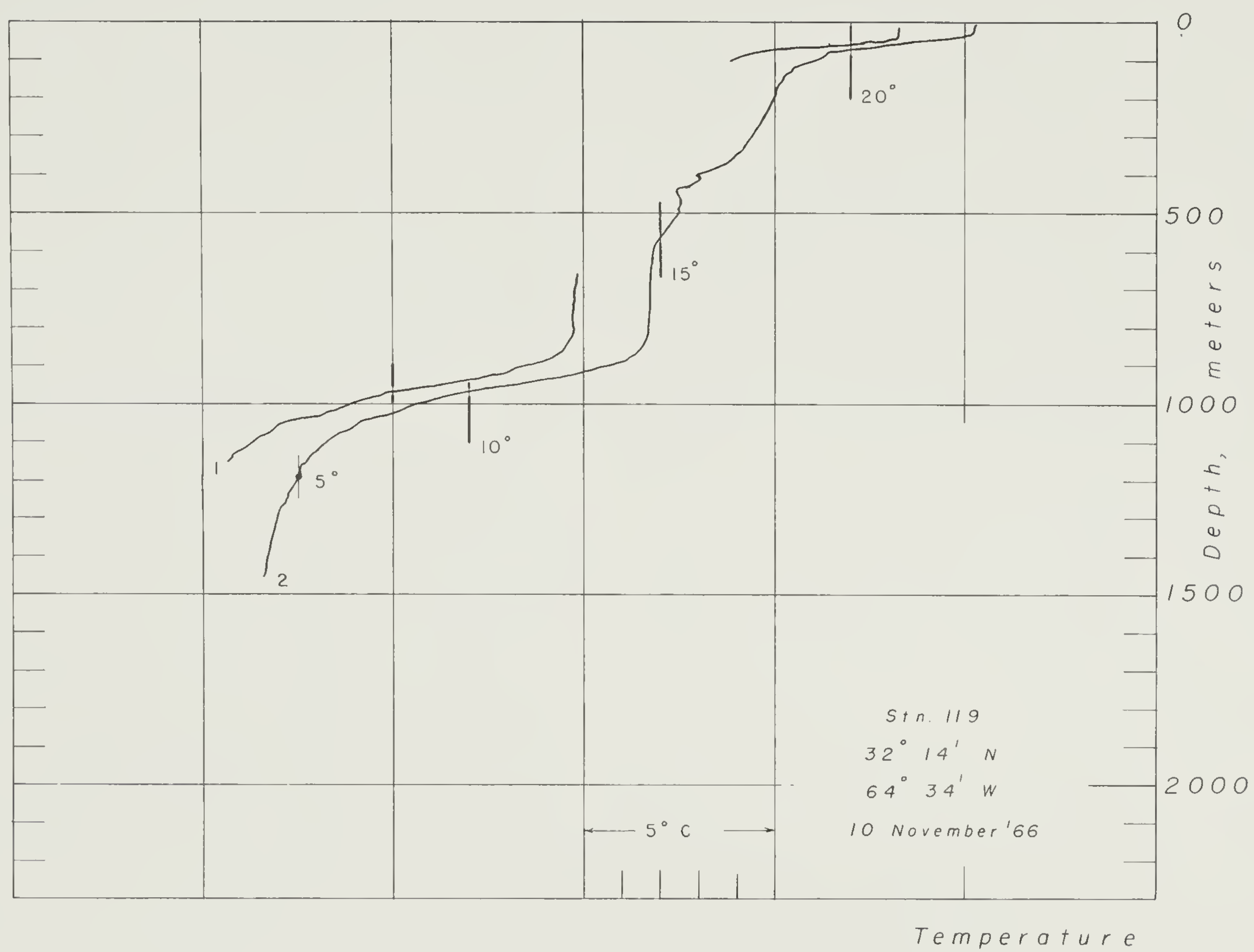


Fig. 31 *Temperatures* – Station 119

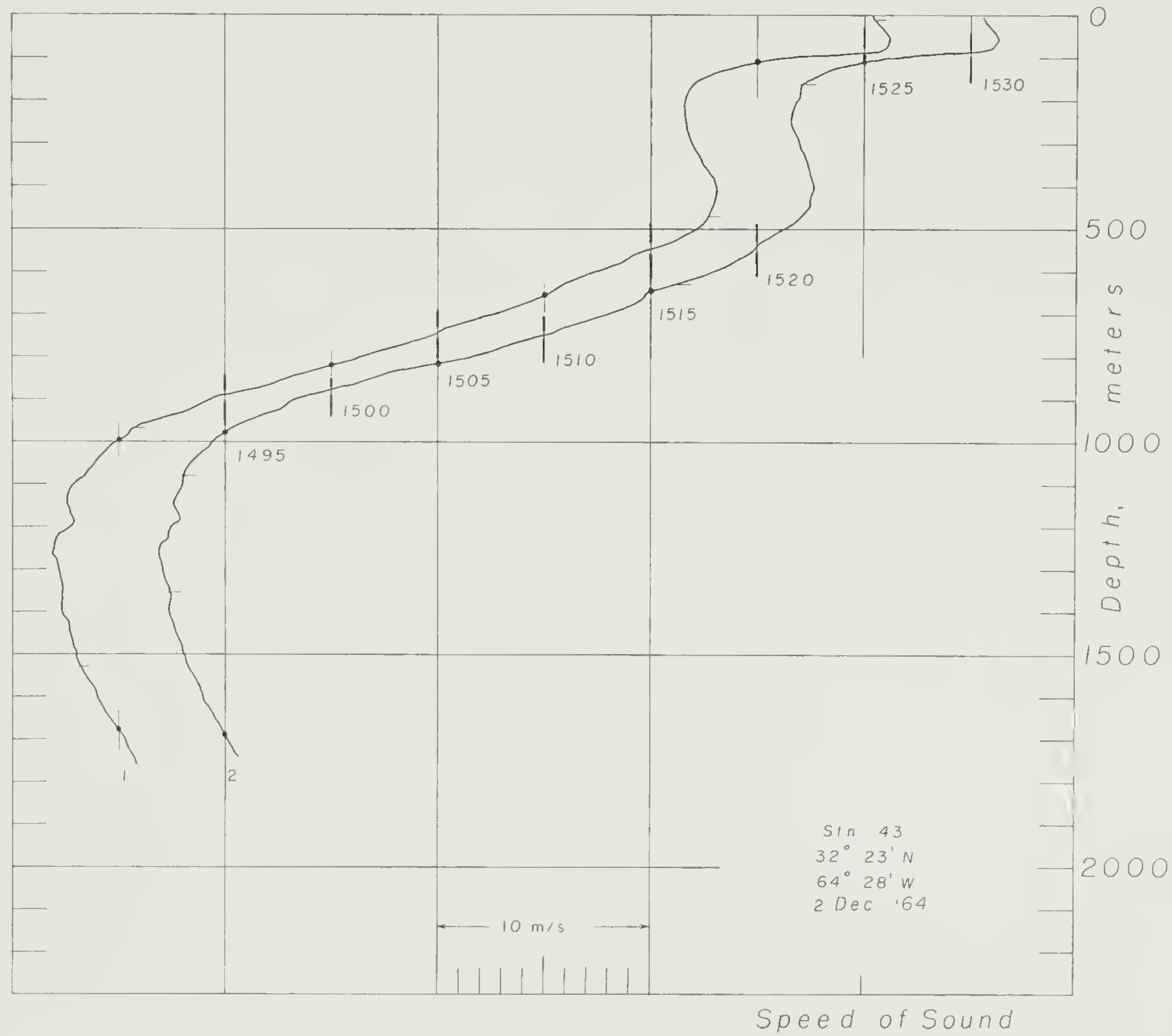


Fig. 32 *Sound Speeds – Station 43*

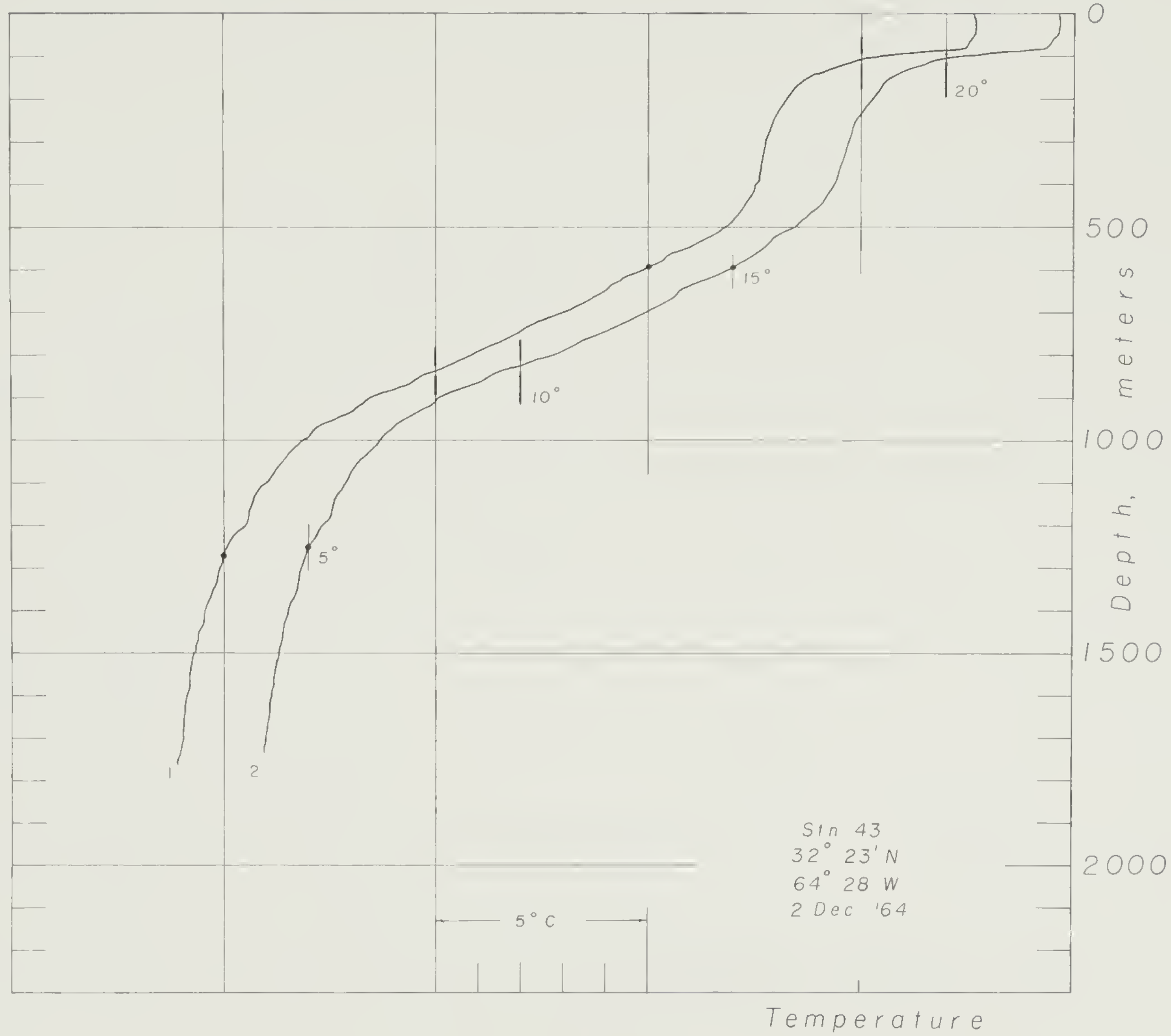


Fig. 33 *Temperatures – Station 43*

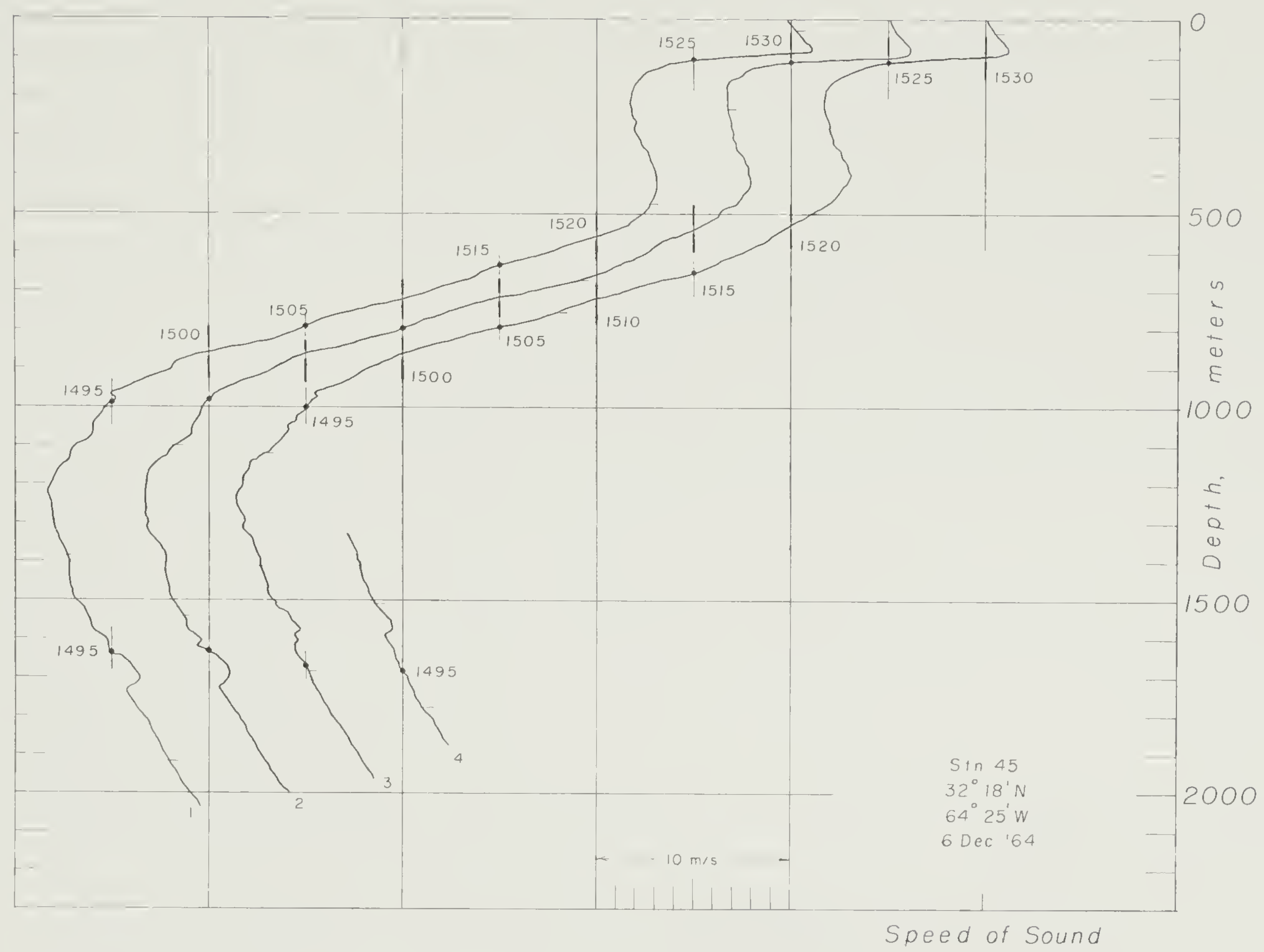


Fig. 34 *Sound Speeds* – Station 45

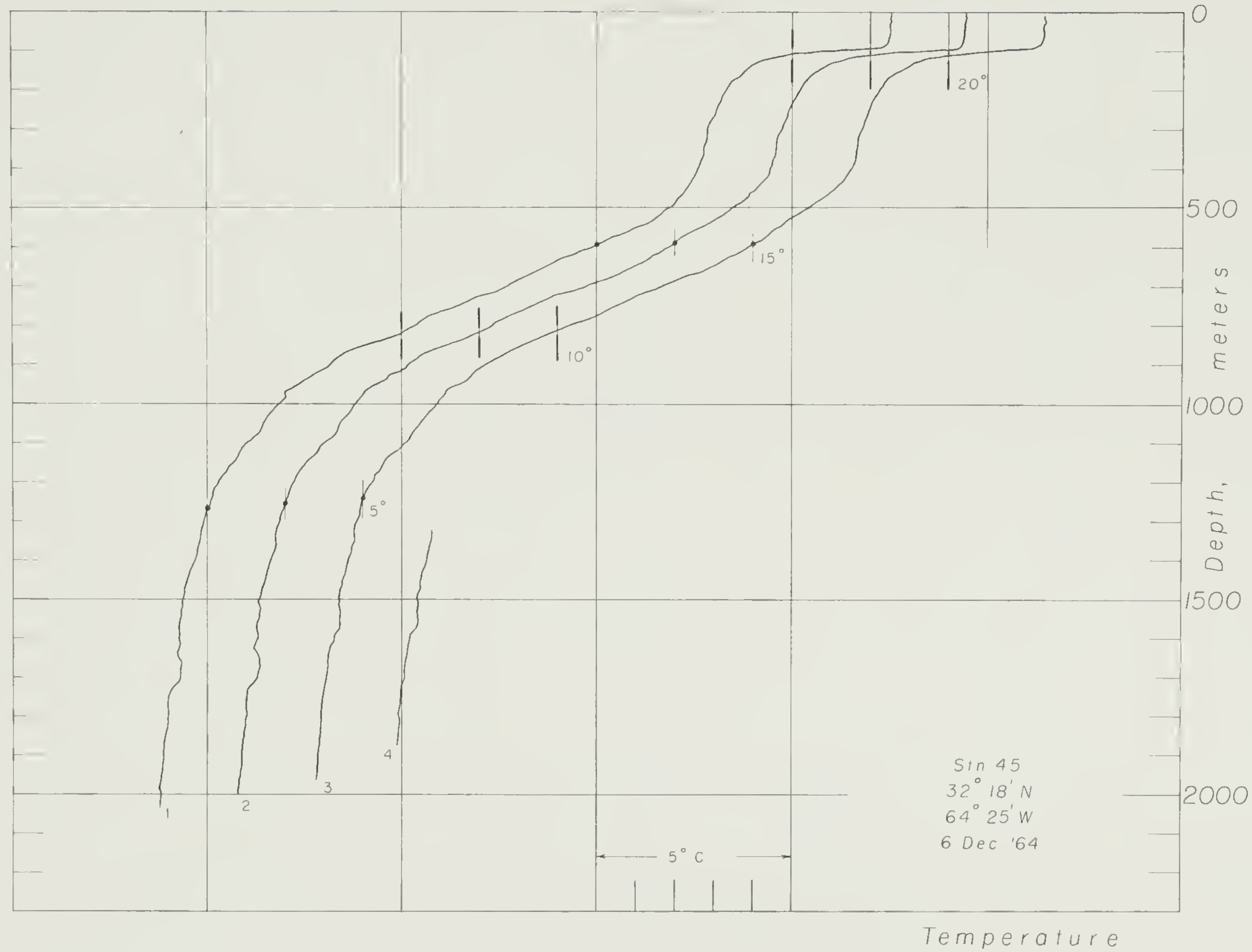


Fig. 35 *Temperatures – Station 45*

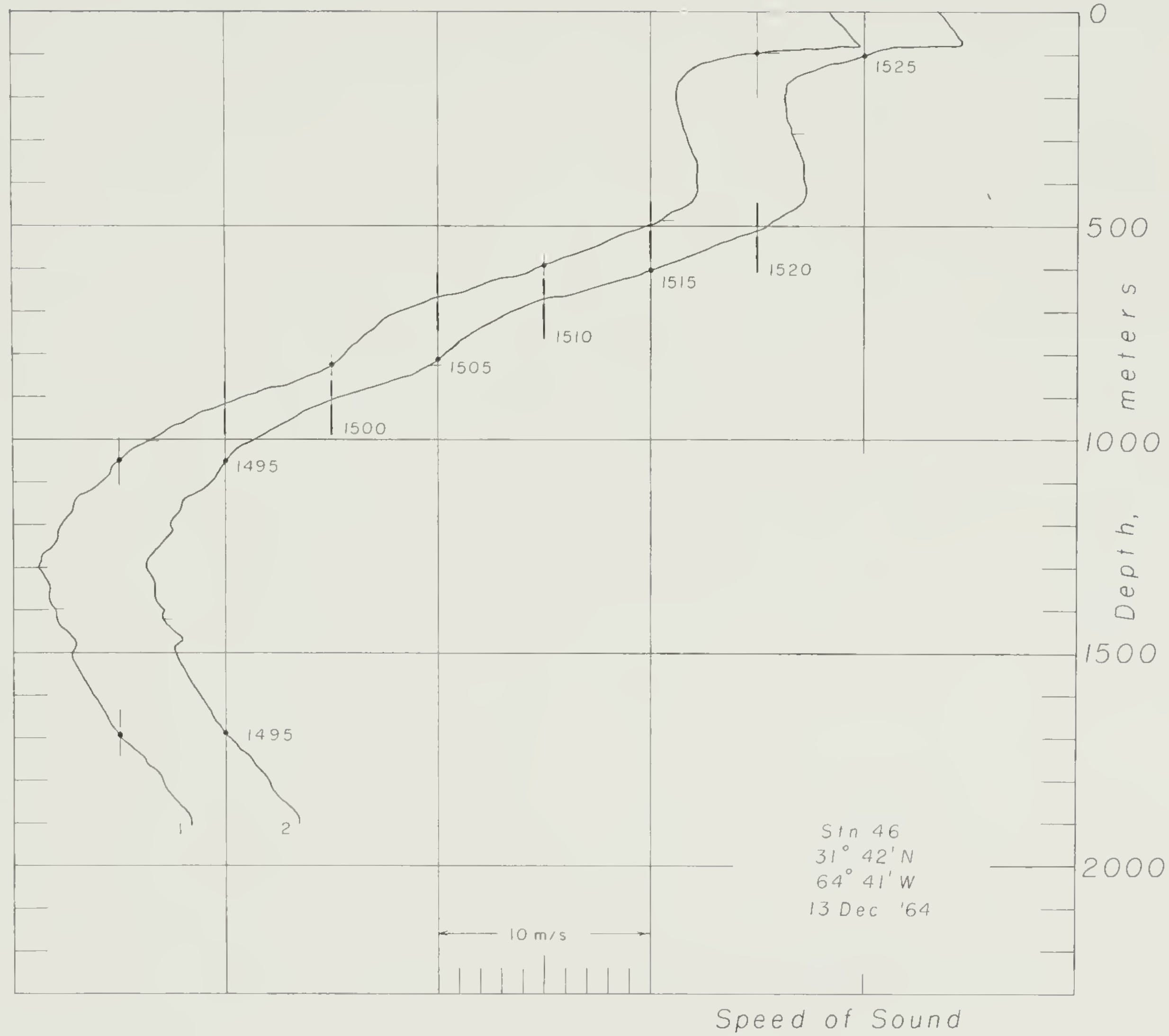


Fig. 36 *Sound Speeds* – Station 46

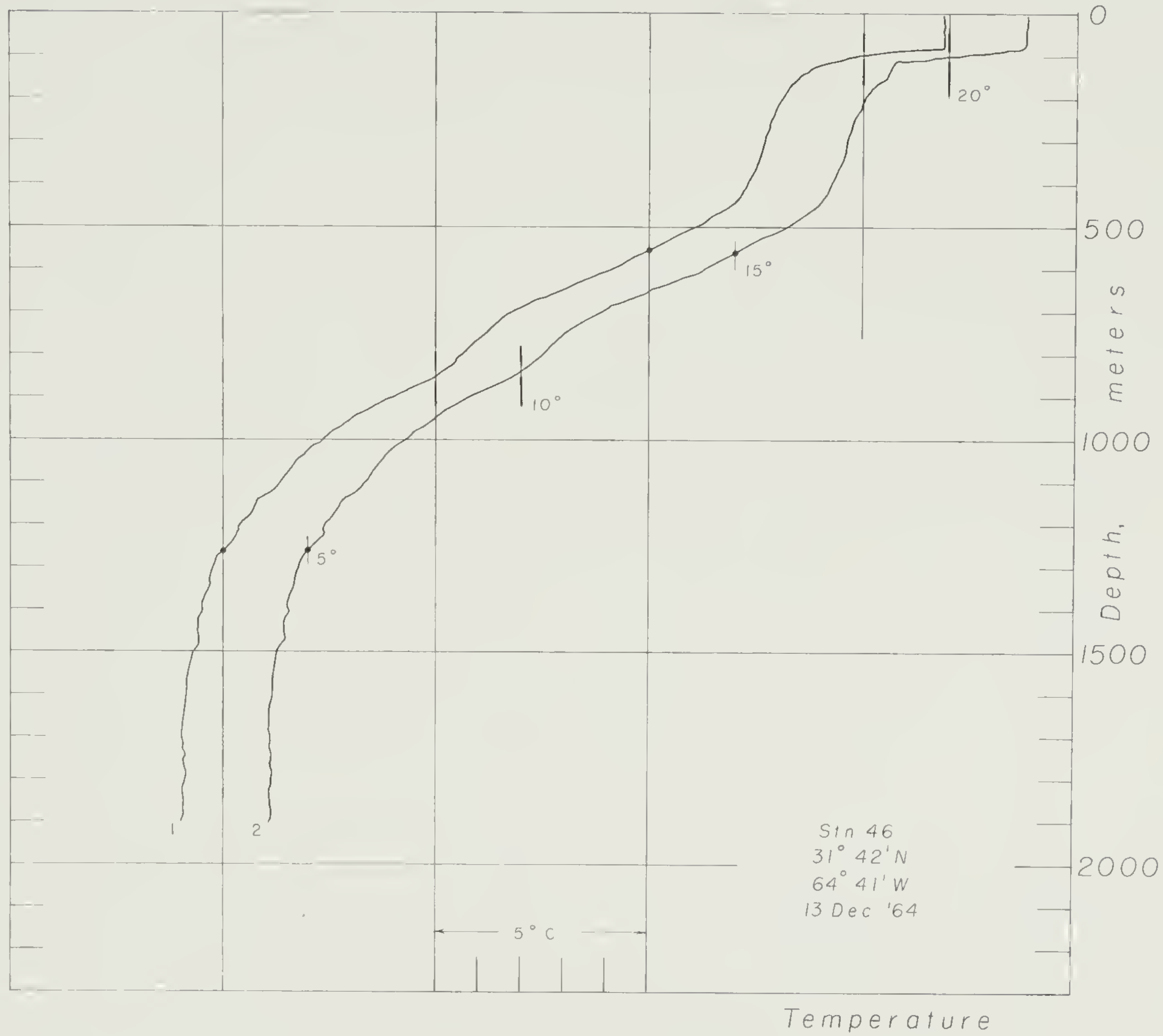


Fig. 37 *Temperatures* – Station 46

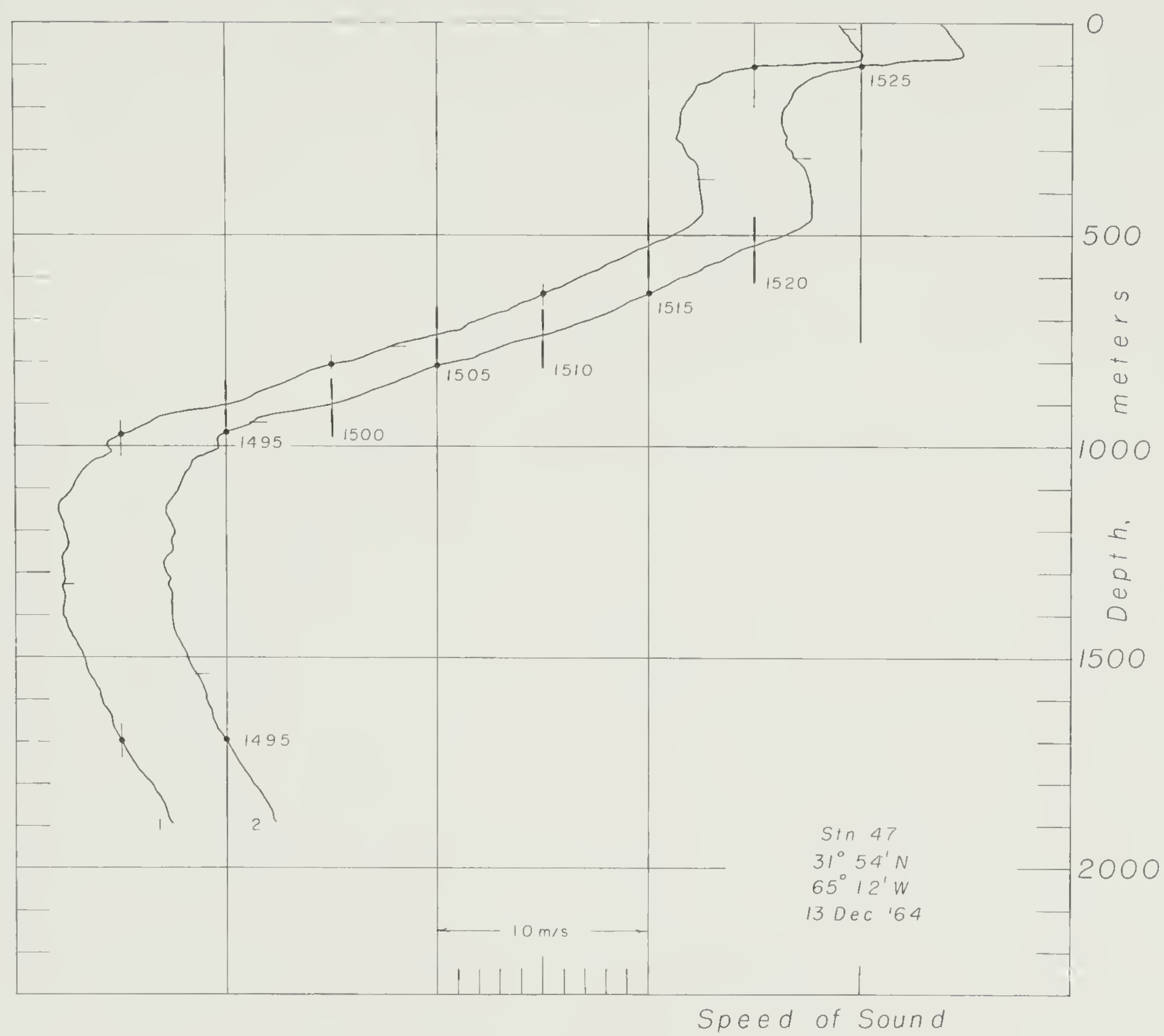


Fig. 38 *Sound Speeds – Station 47*

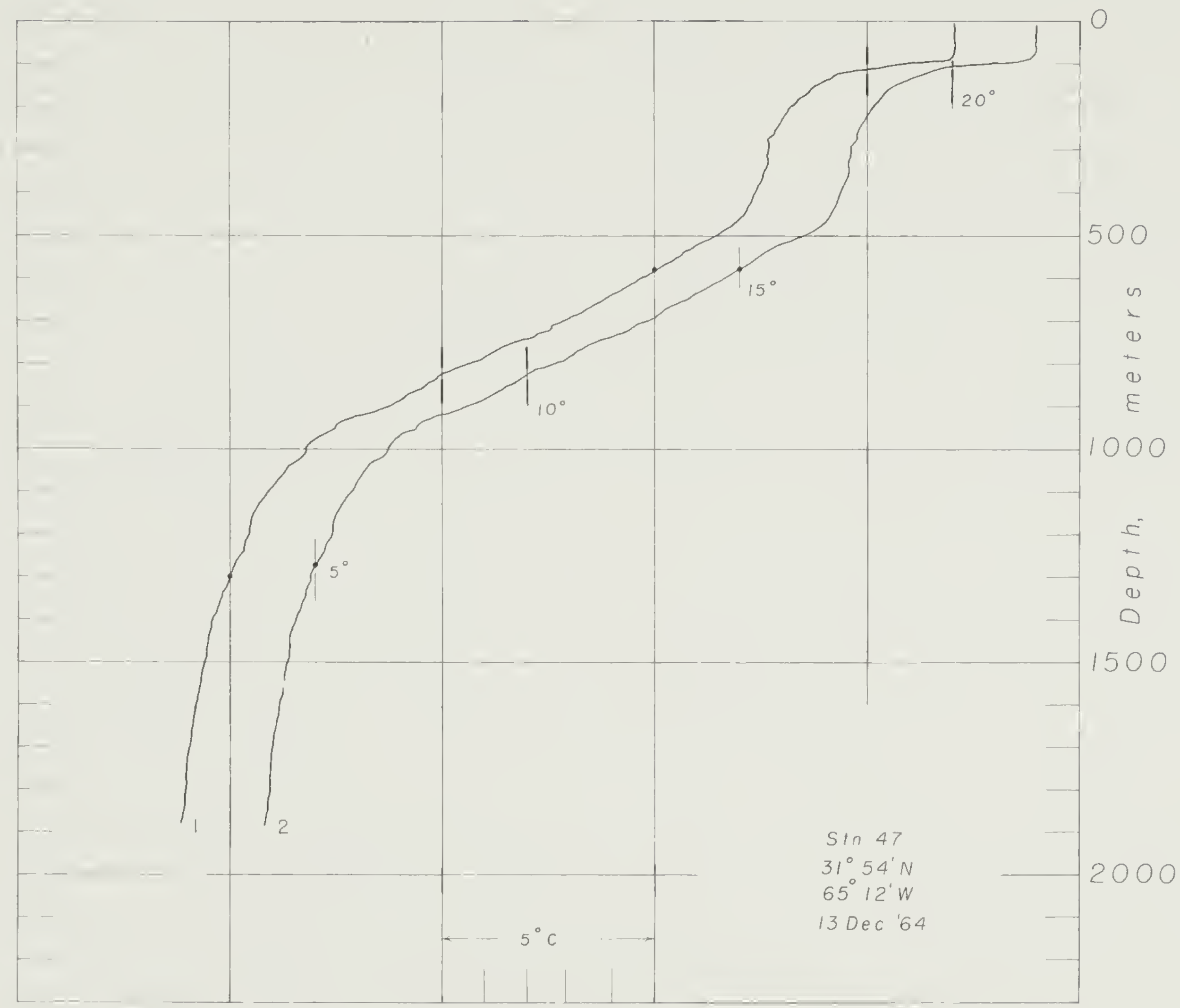


Fig. 39 *Temperatures – Station 47*

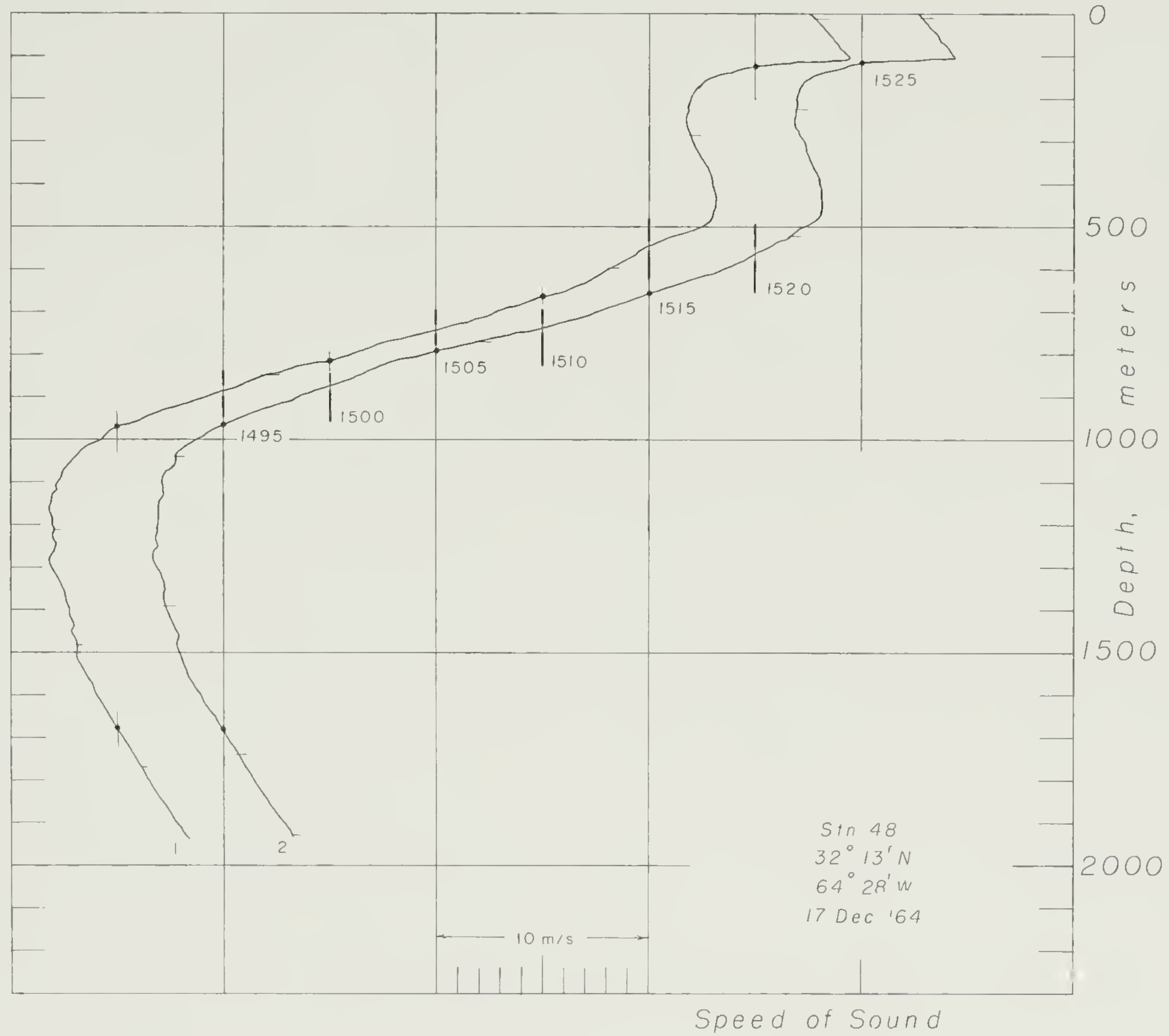


Fig. 40 *Sound Speeds* – Station 48

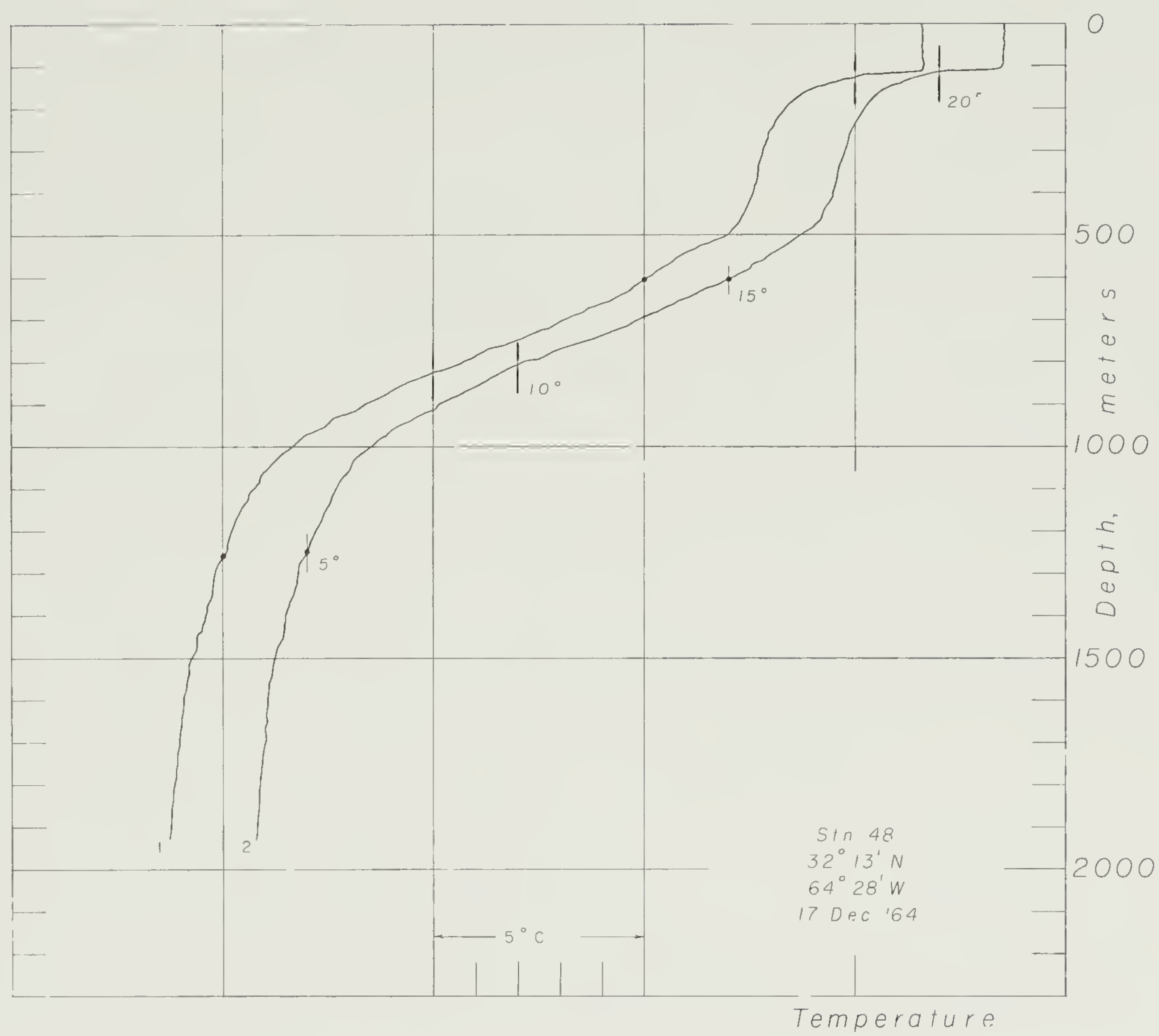


Fig. 41 *Temperatures* – Station 48

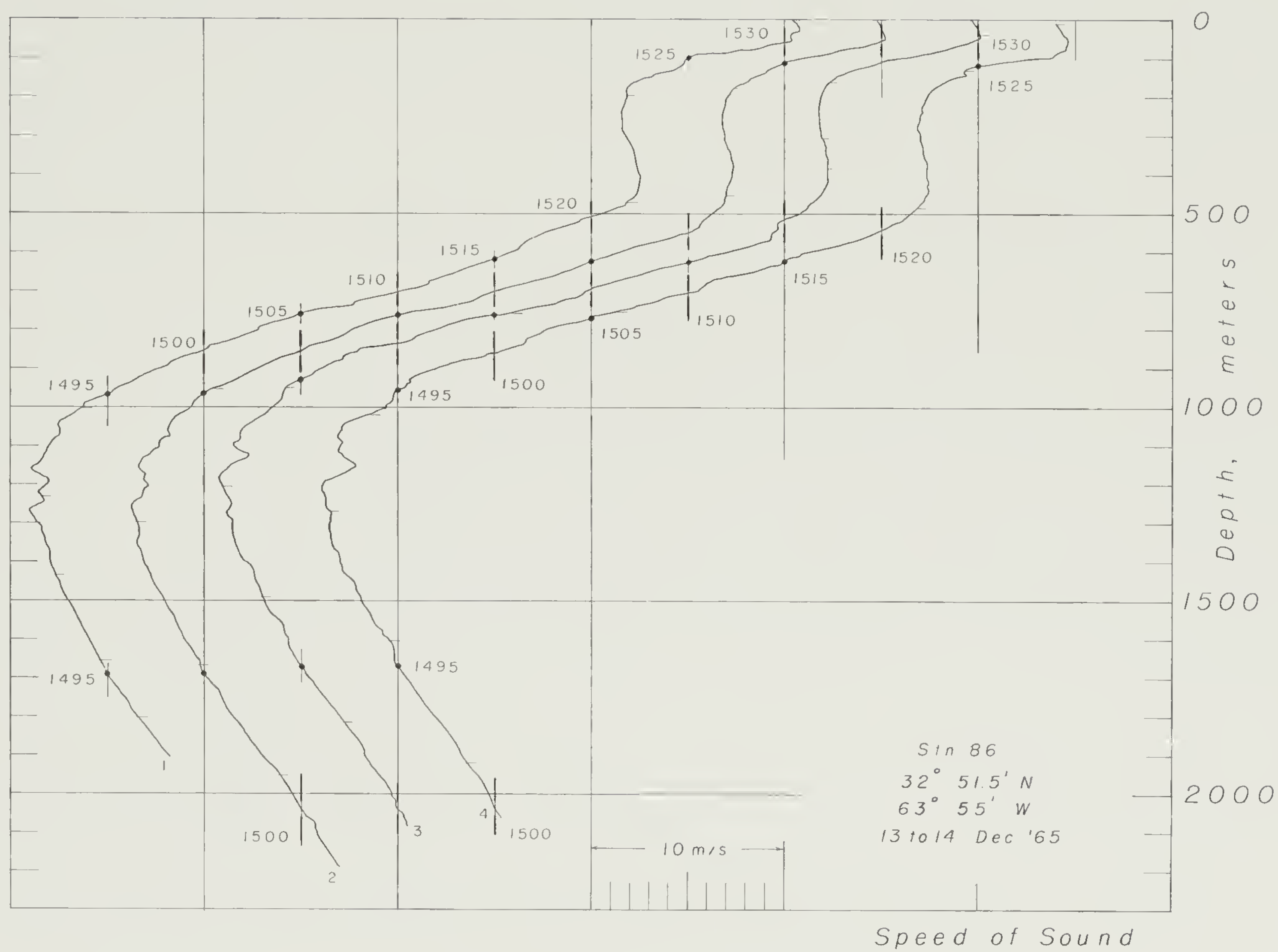


Fig. 42 *Sound Speeds* – Station 86

Fig. 43 *Temperatures* – Station 86

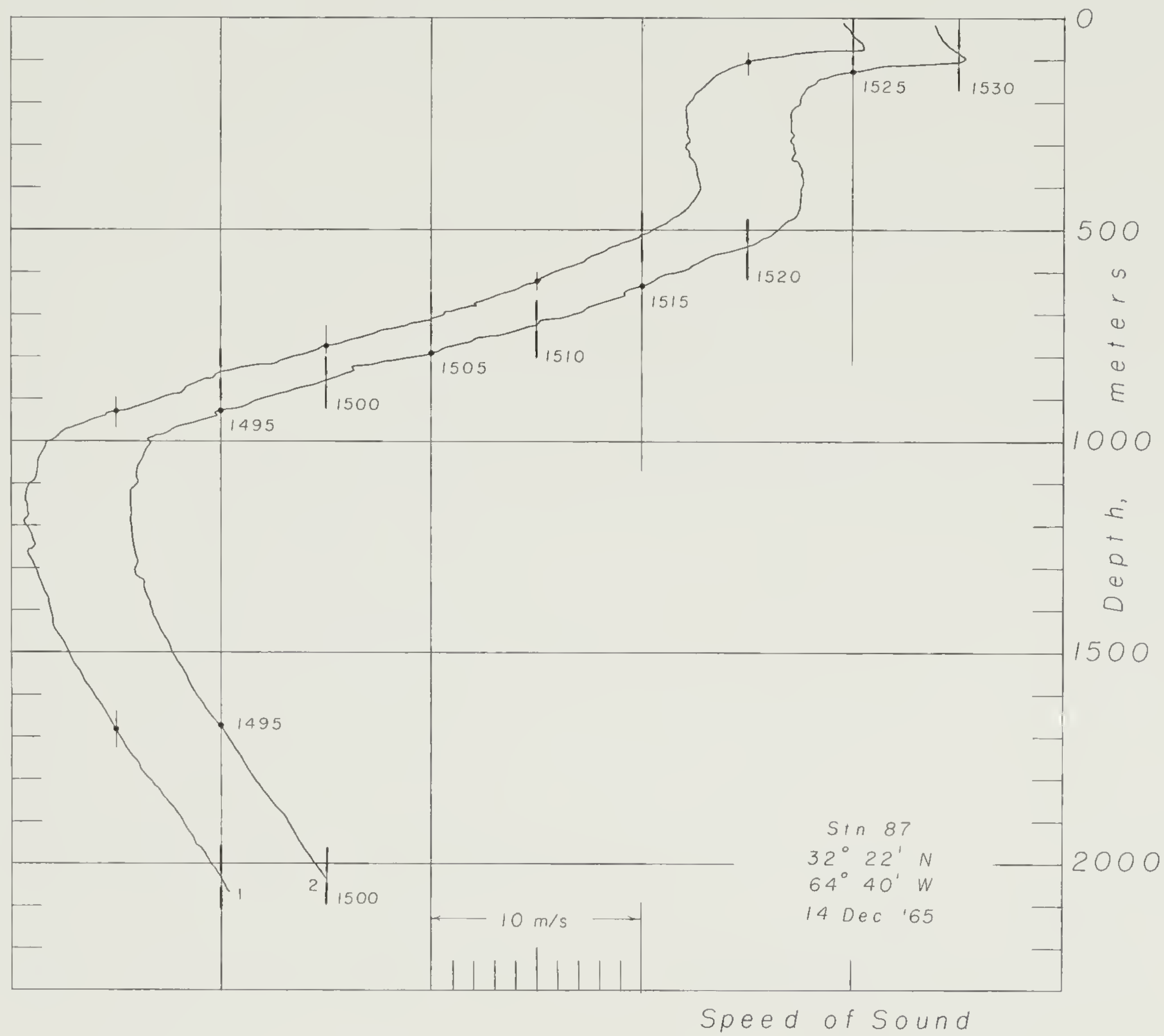


Fig. 44 *Sound Speeds* – Station 87

Fig. 45 *Temperatures* – Station 87

Fig. 46 *Sound Speeds* – Station 88

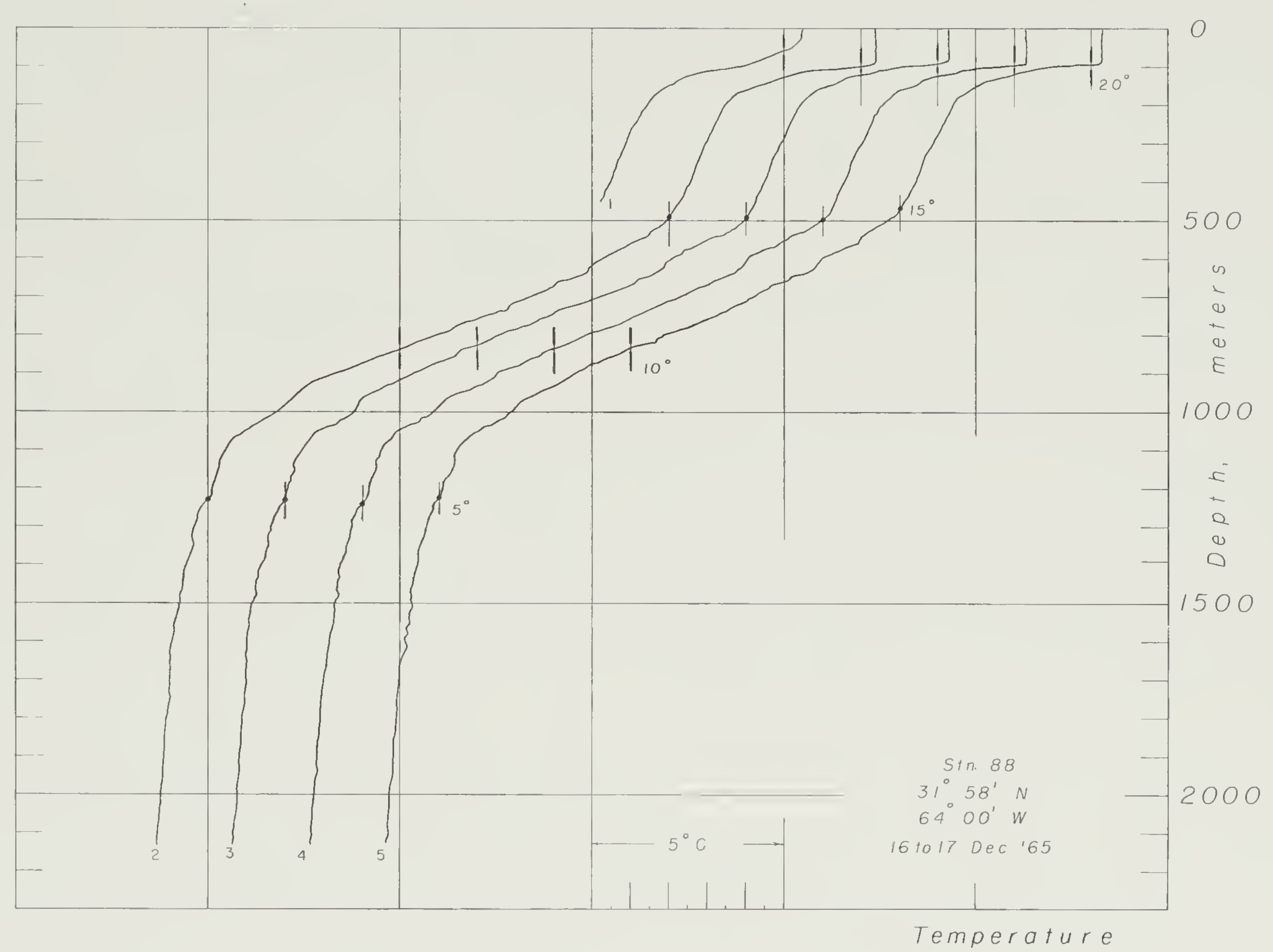


Fig. 47 *Temperatures* – Station 88

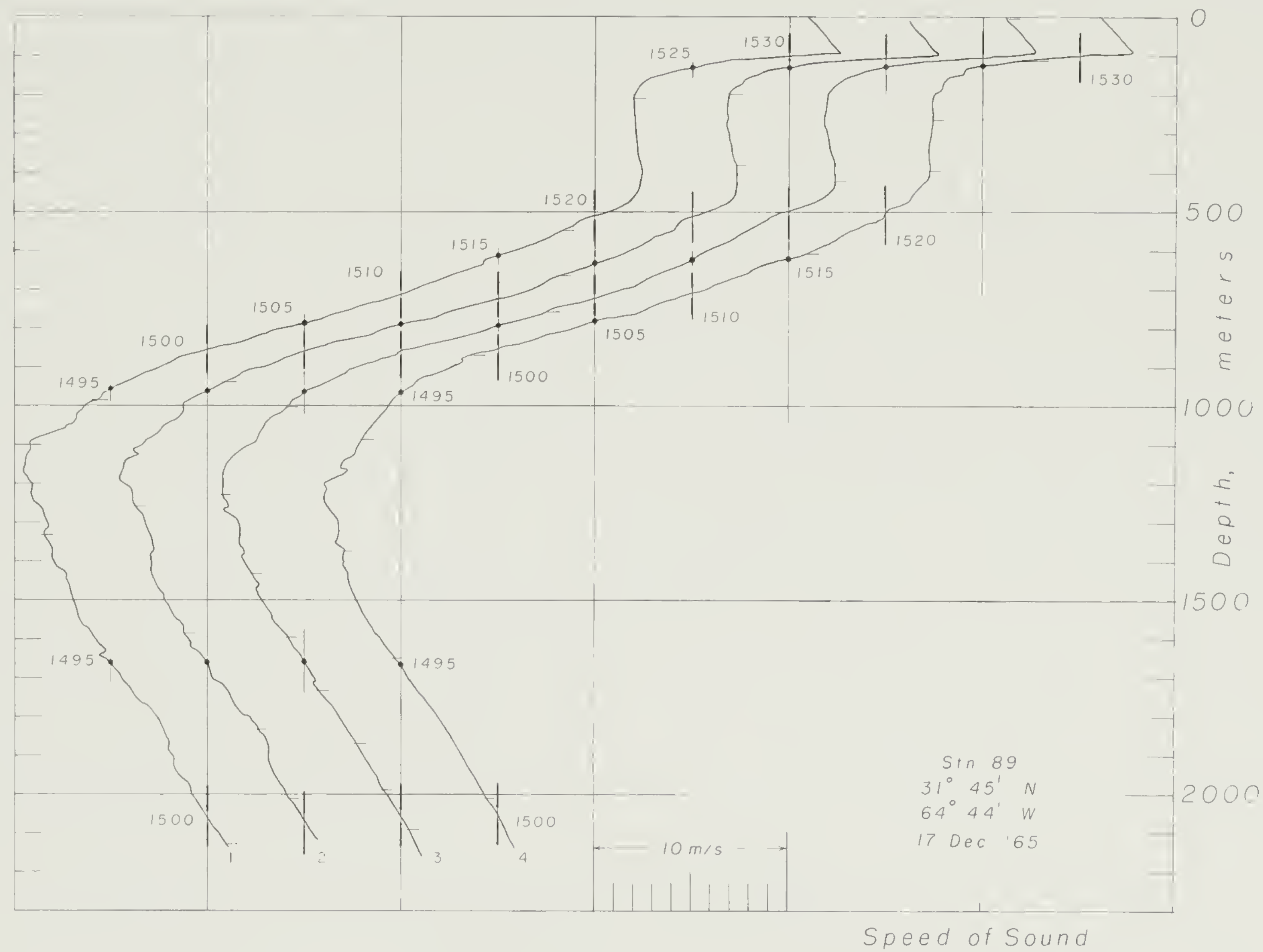


Fig. 48 *Sound Speeds* – Station 89

Fig. 49 *Temperatures* – Station 89

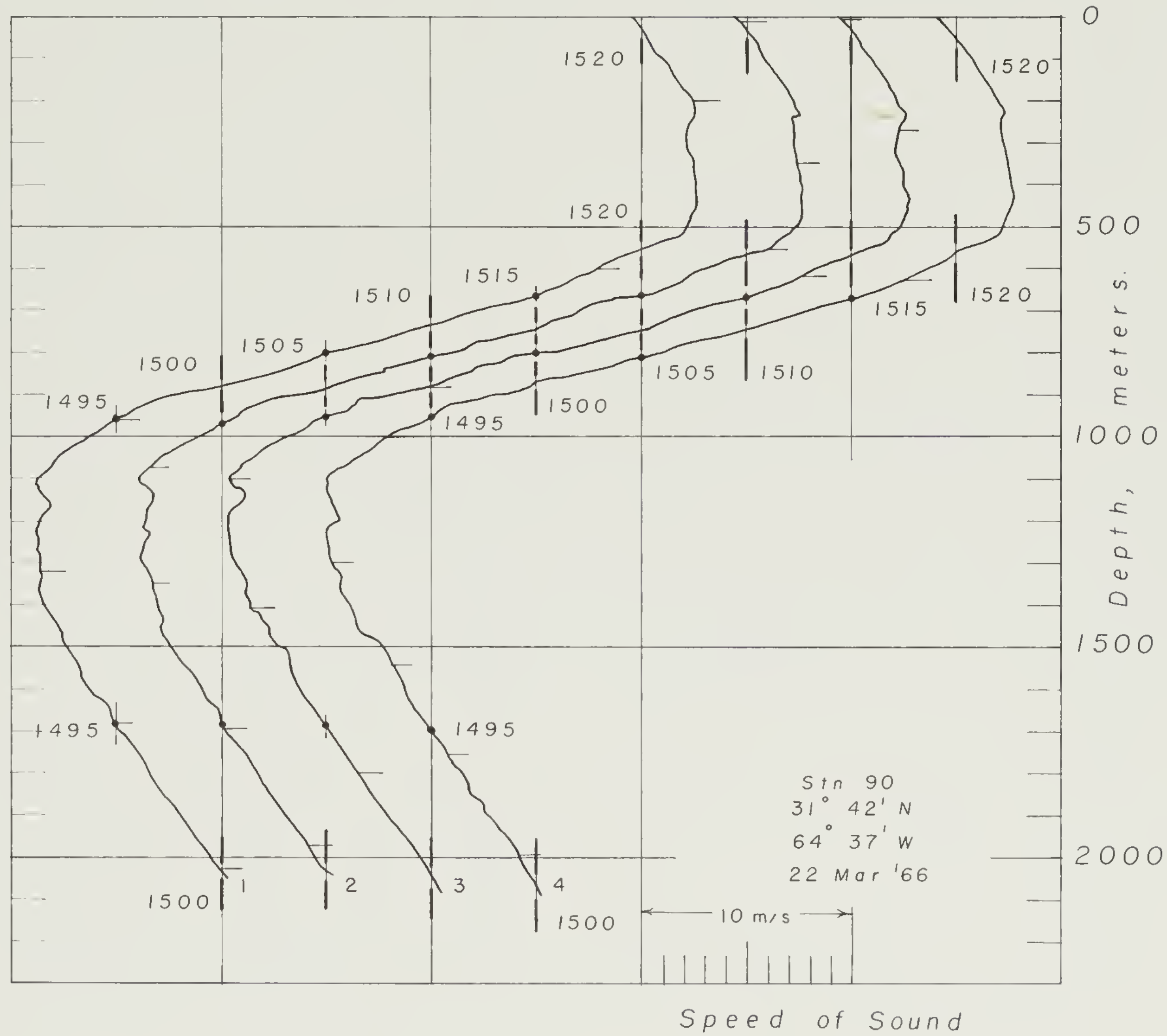


Fig. 50 *Sound Speeds* – Station 90

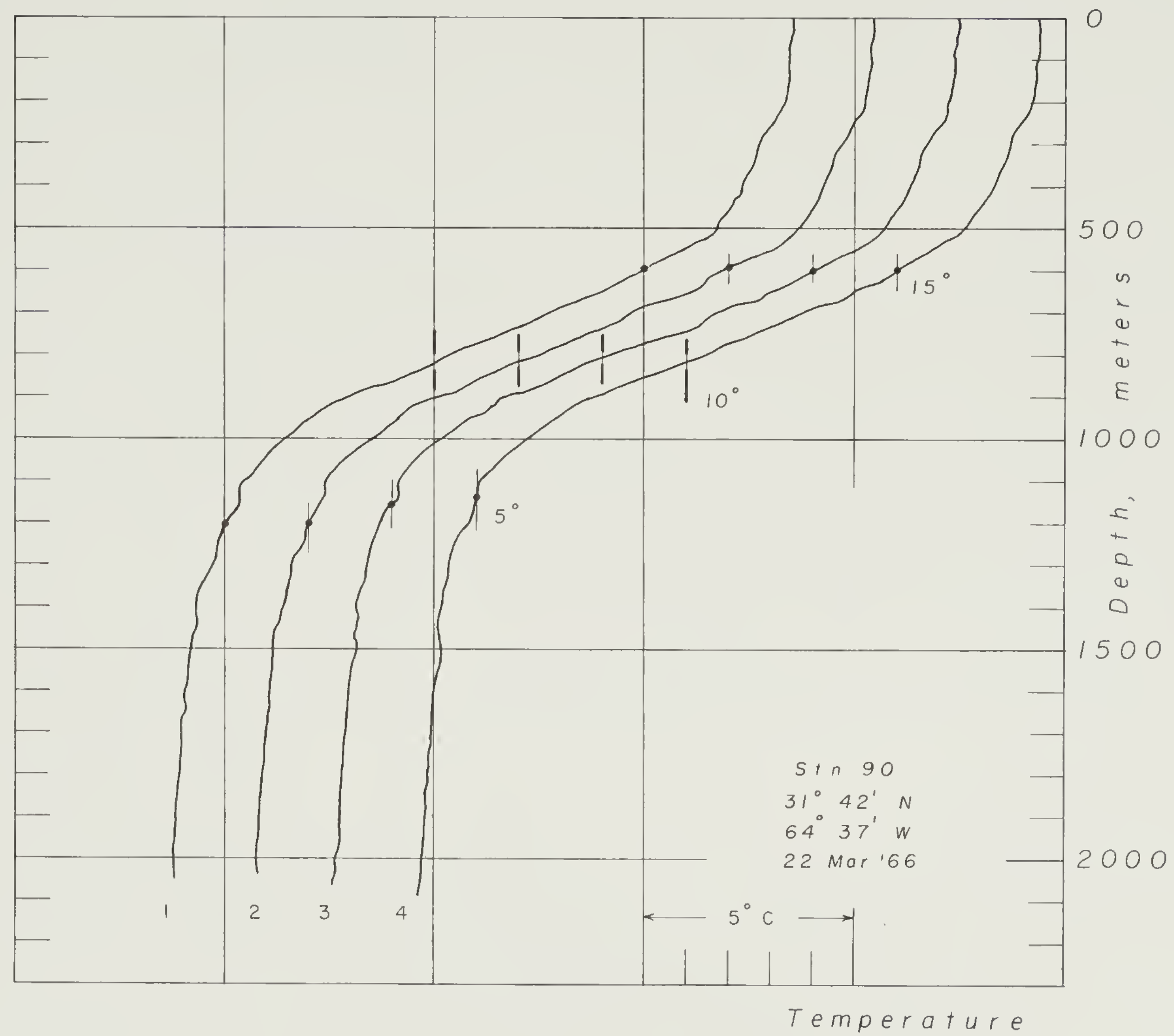


Fig. 51 *Temperatures — Station 90*

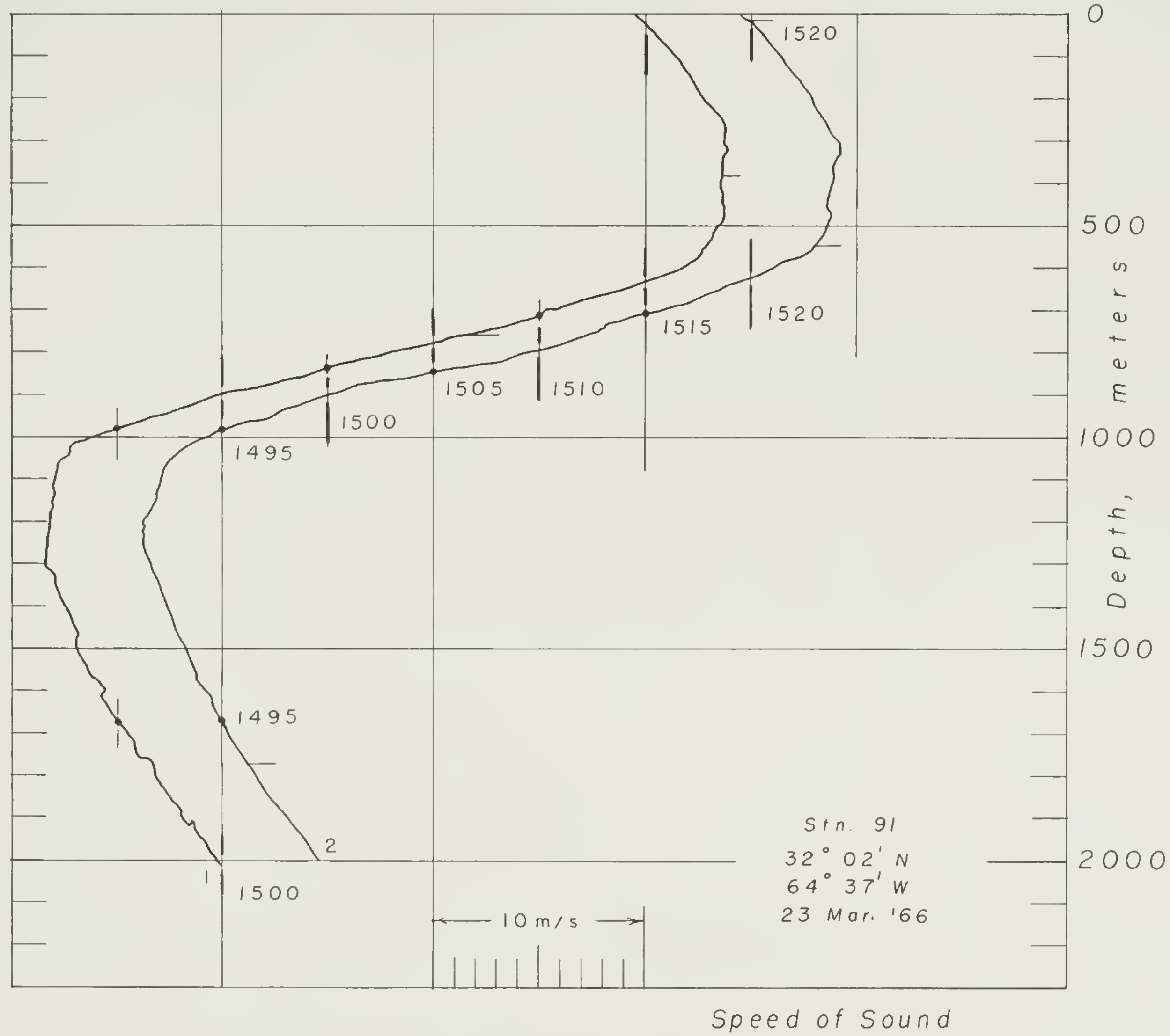


Fig. 52 *Sound Speeds* – Station 91

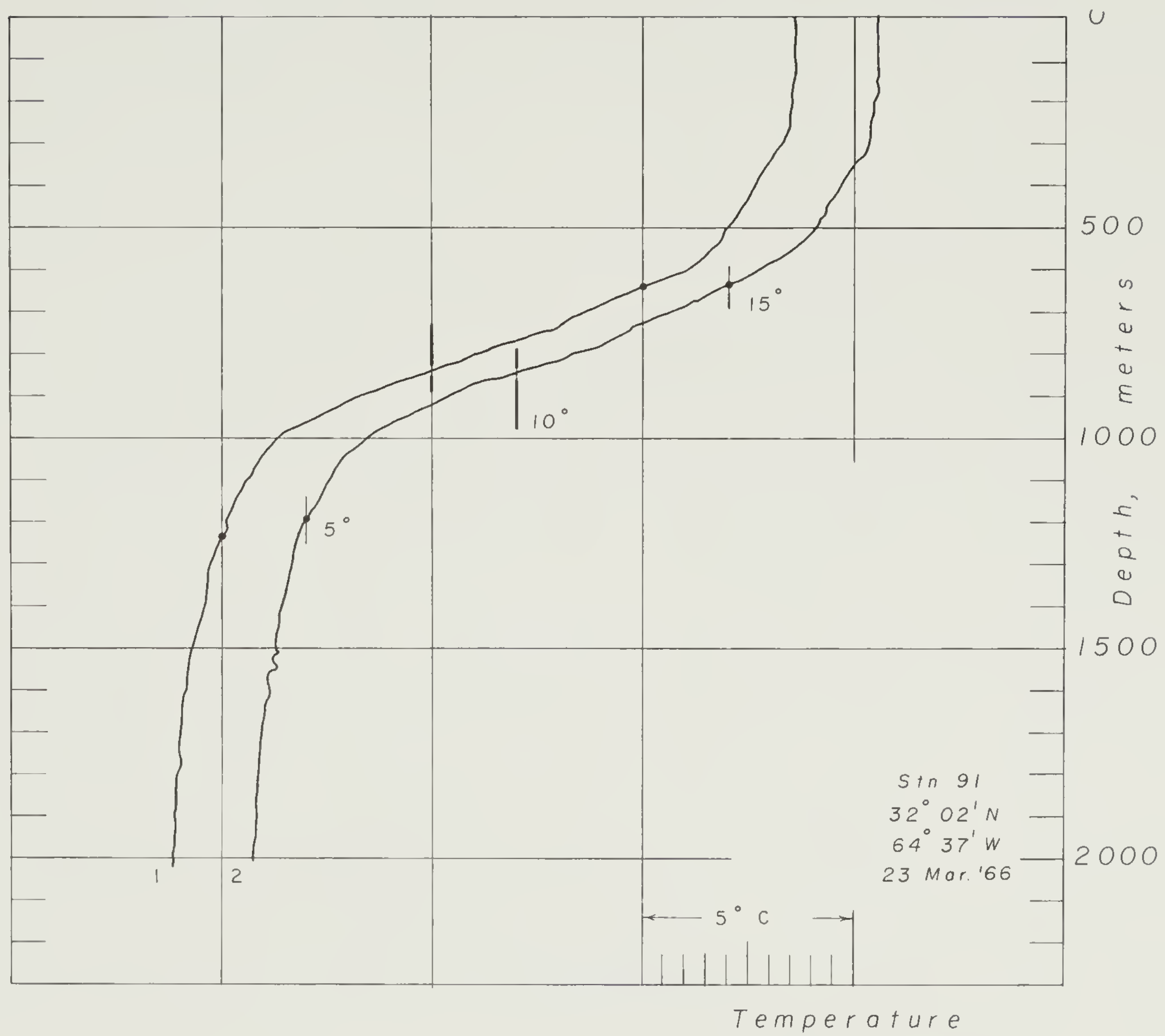


Fig. 53 *Temperatures – Station 91*

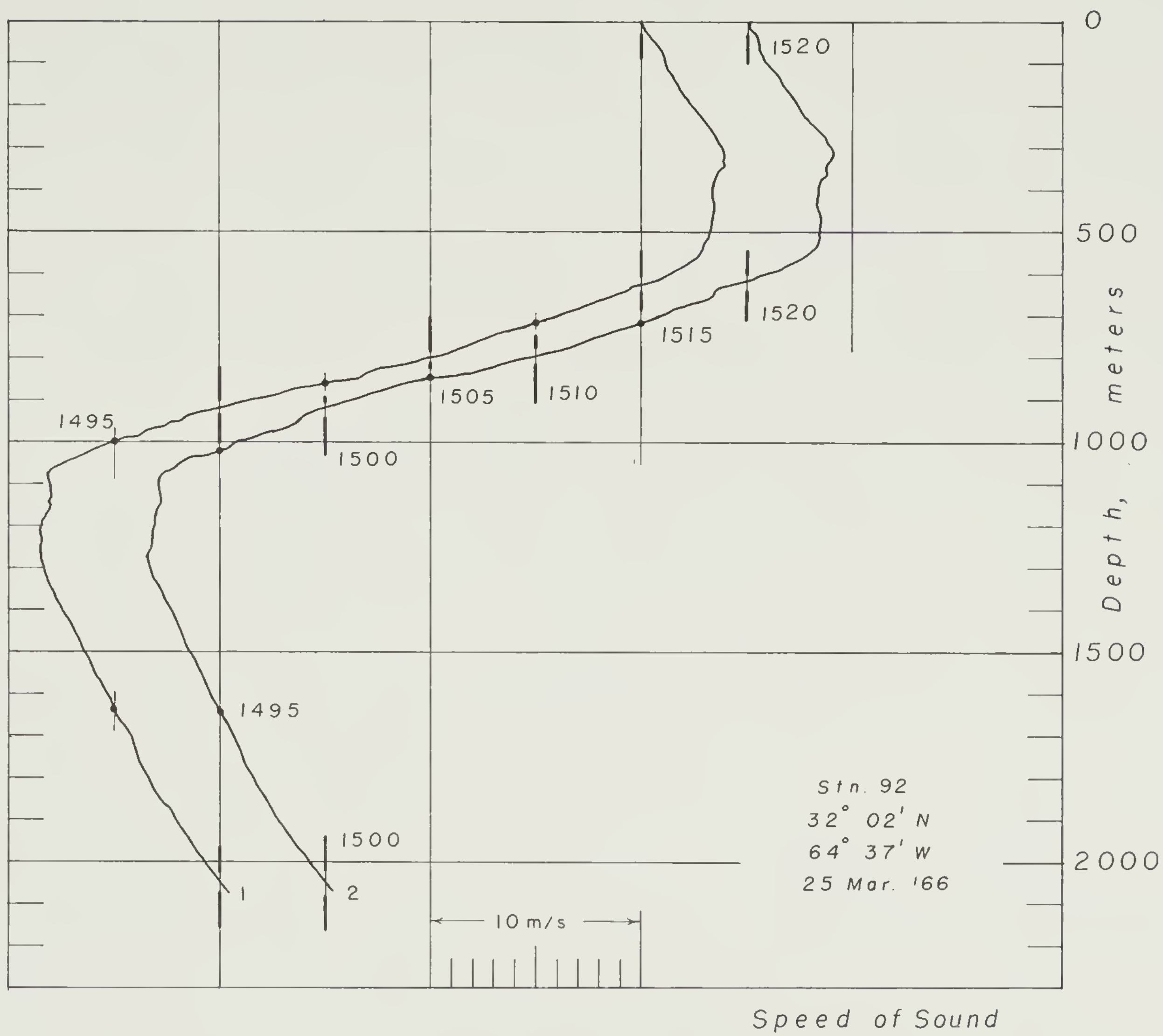


Fig. 54 *Sound Speeds* – Station 92

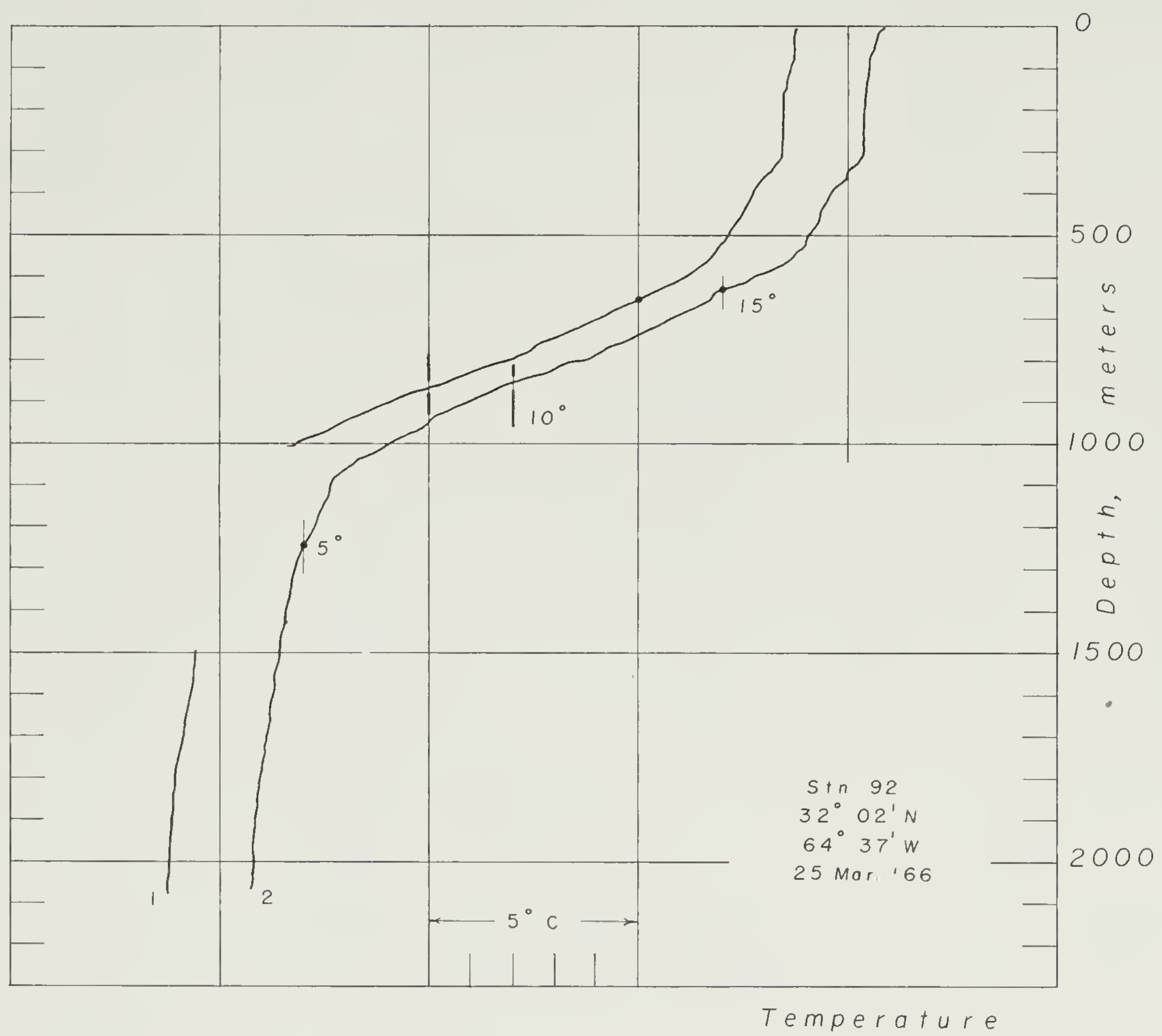


Fig. 55 Temperatures – Station 92

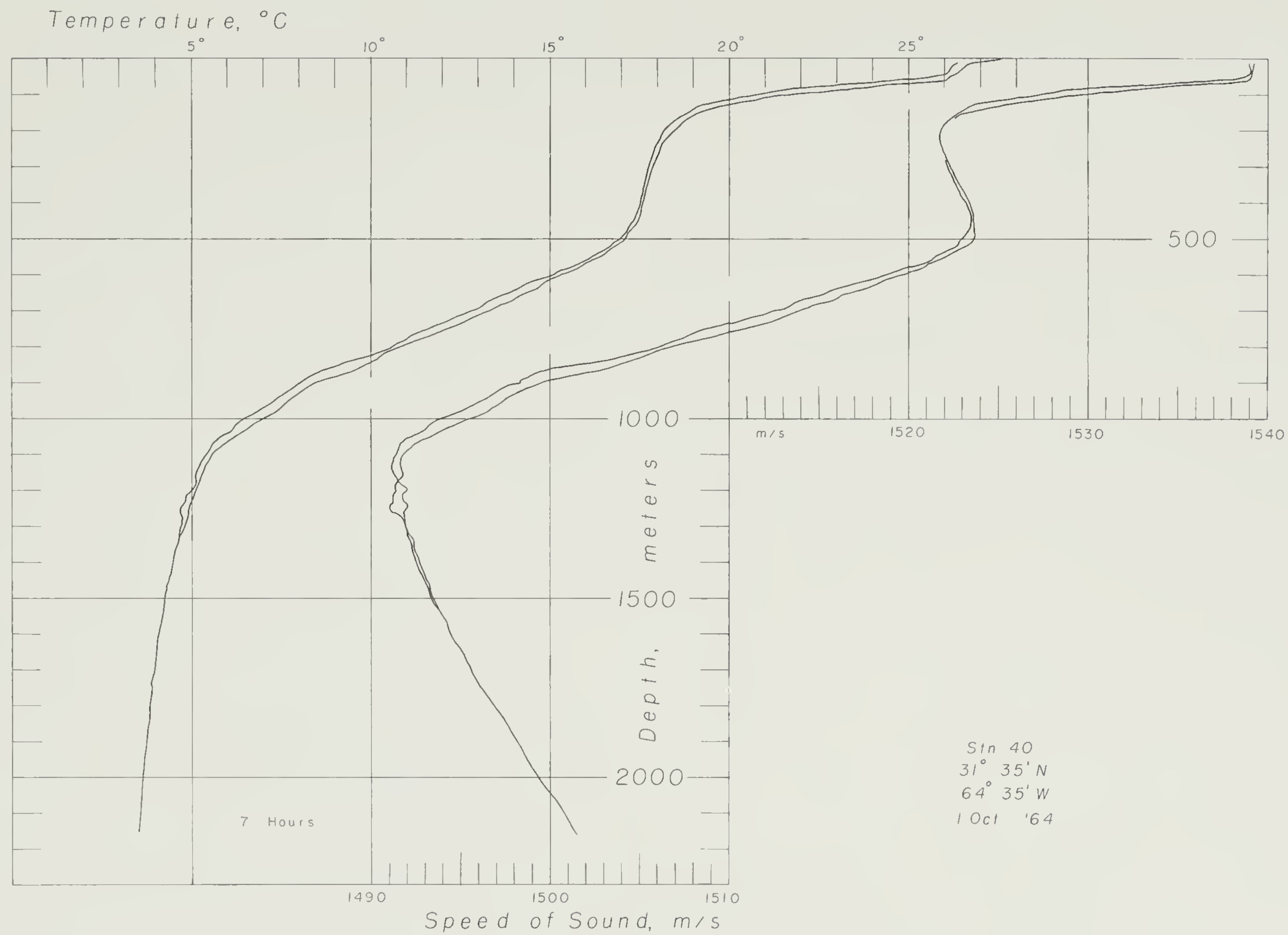


Fig. 56 *Profile Envelopes* – Station 40

Fig. 57 *Profile Envelopes – Station 41*

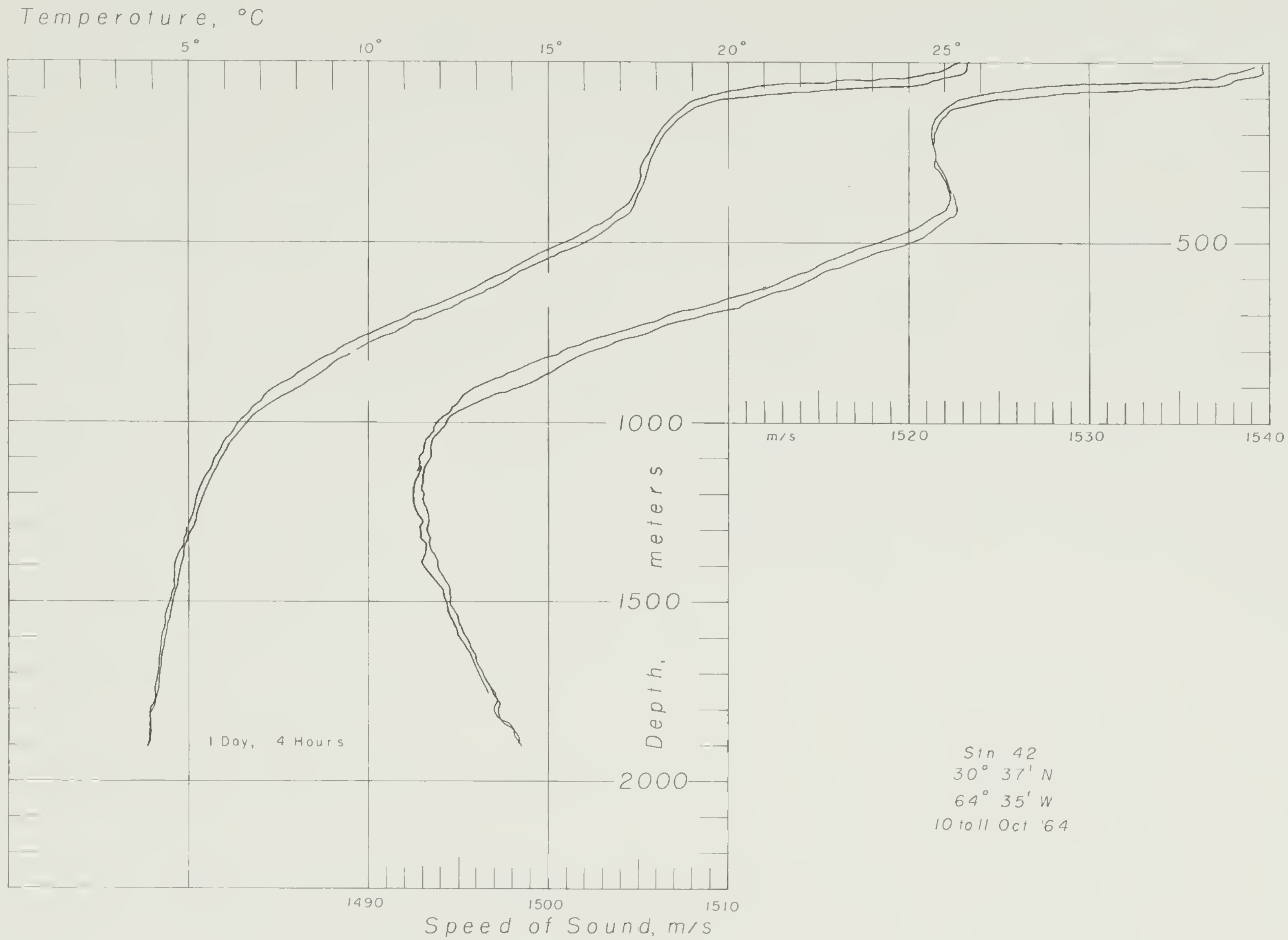


Fig. 58 *Profile Envelopes – Station 42*

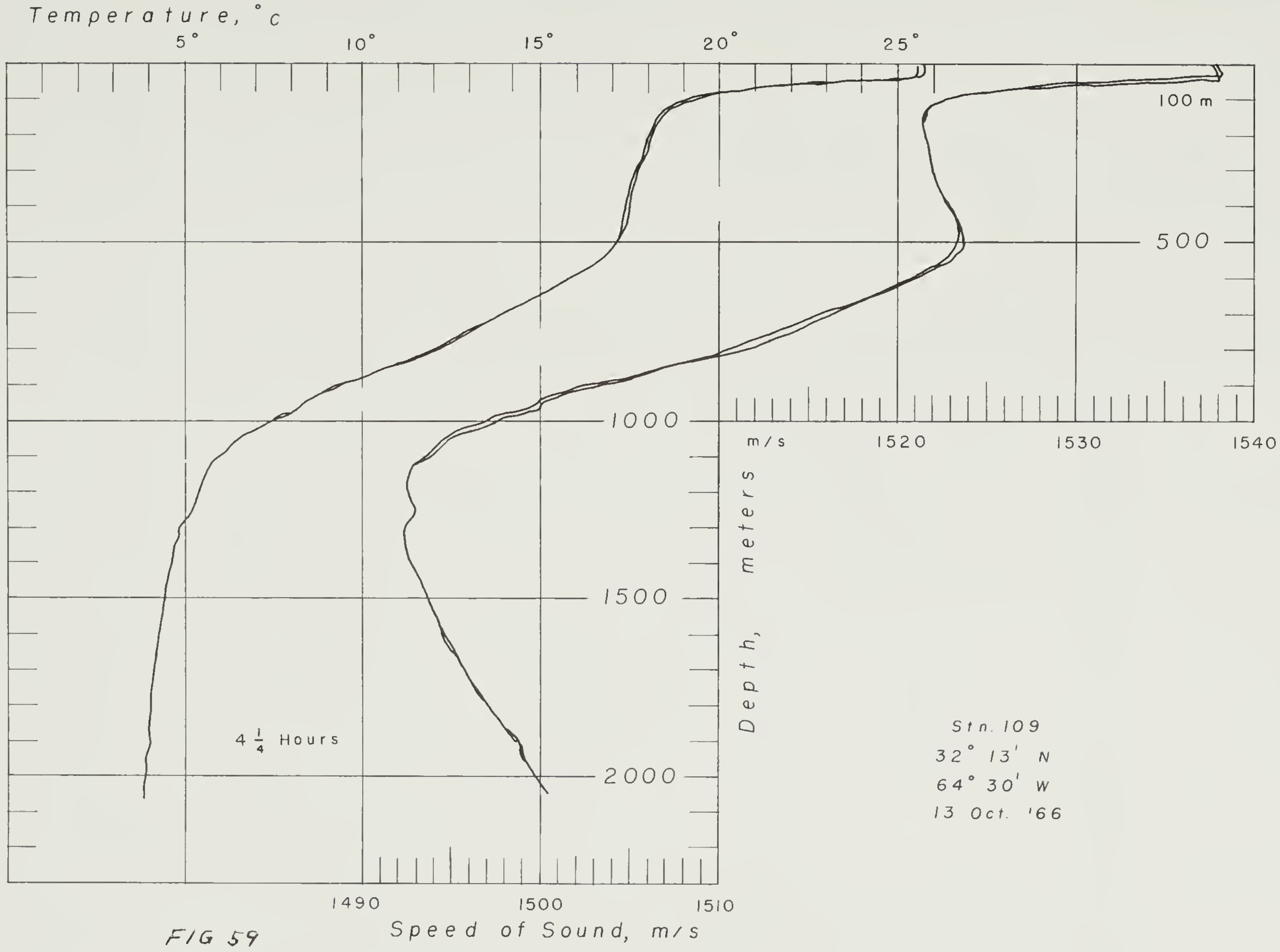


Fig. 59 *Profile Envelopes* – Station 109

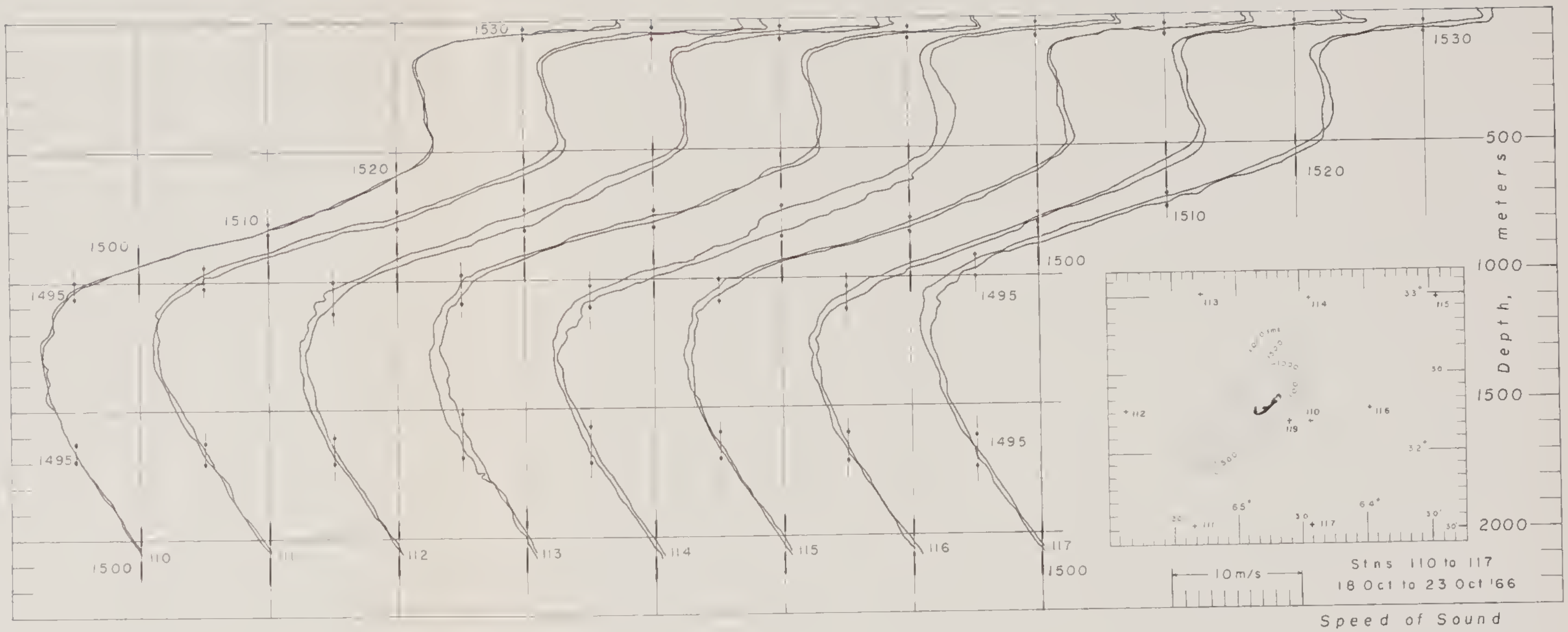


Fig. 60 *Sound Speed Profile Envelopes* — Stations 110 to 117

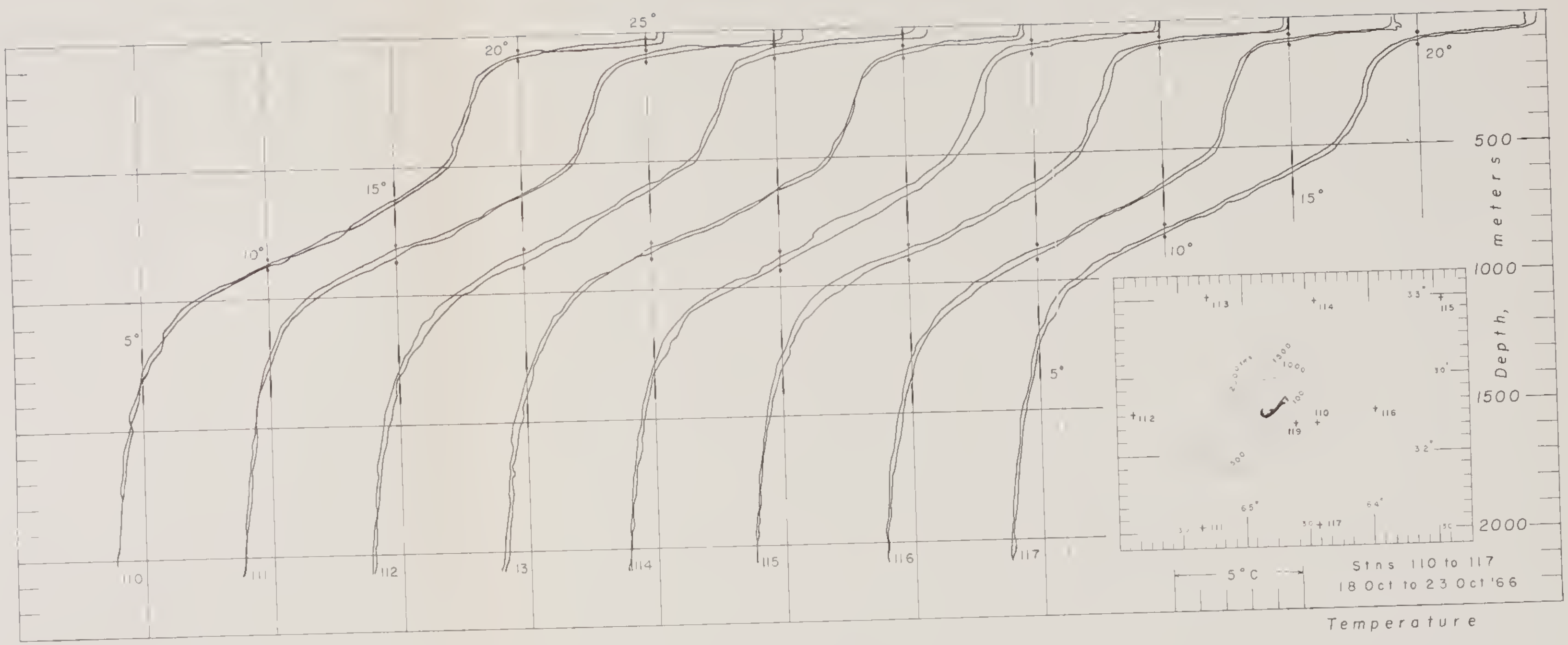


Fig. 61 *Temperature Profile Envelopes* — Stations 110 to 117

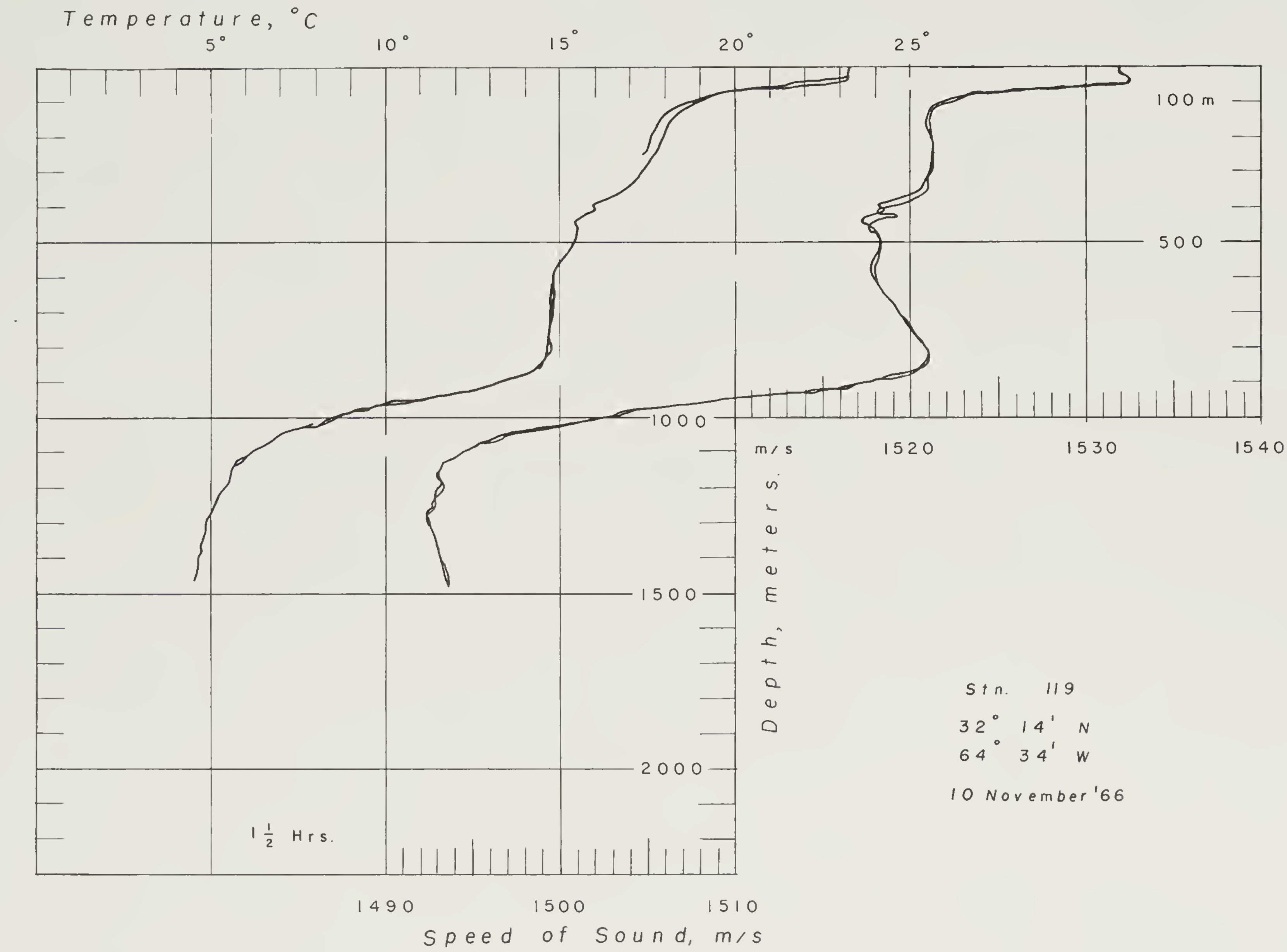


Fig. 62 *Profile Envelopes* – Station 119

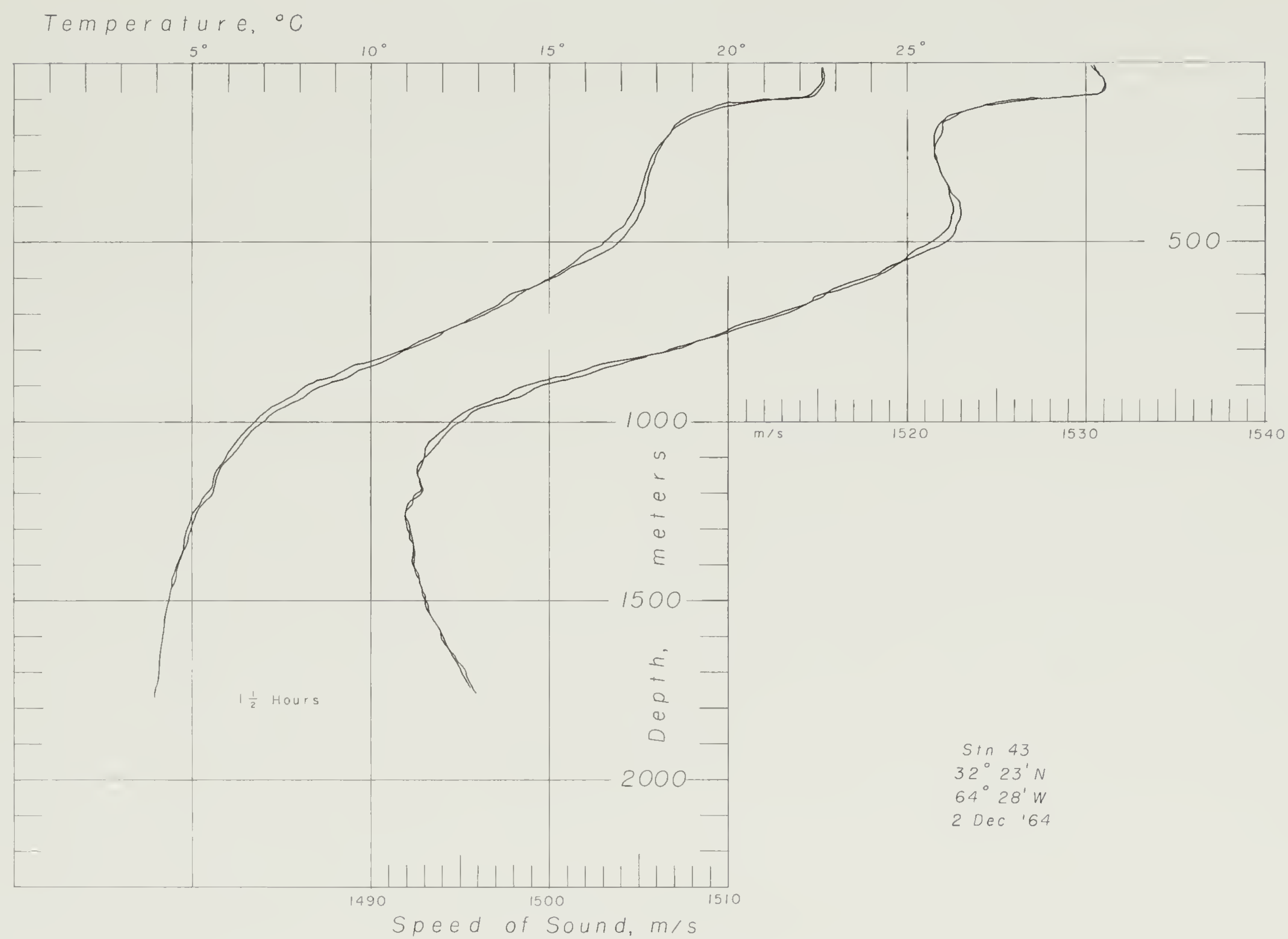


Fig. 63 *Profile Envelopes – Station 43*

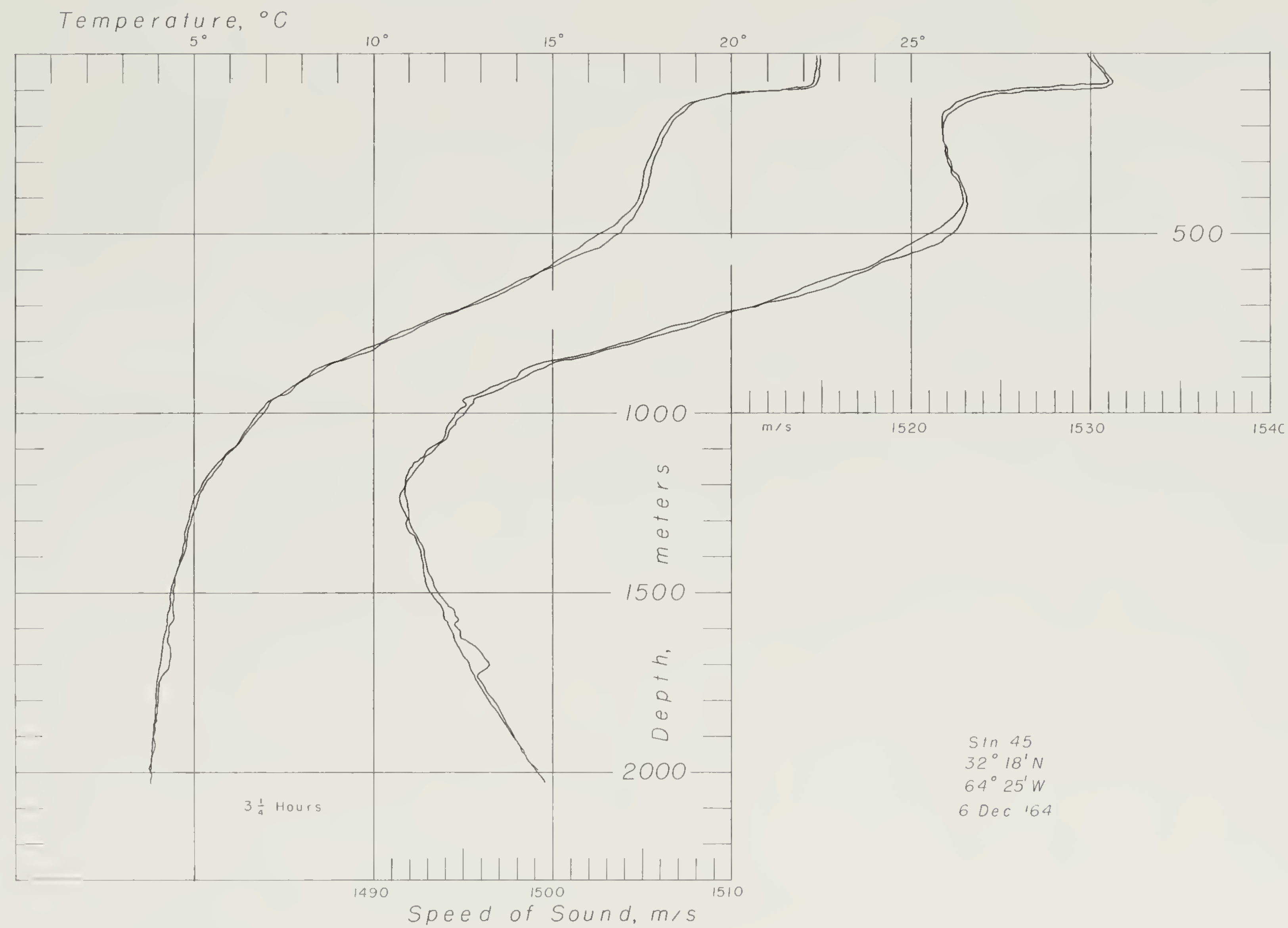


Fig. 64 *Profile Envelopes* – Station 45

Fig. 65 *Profile Envelopes* – Station 46

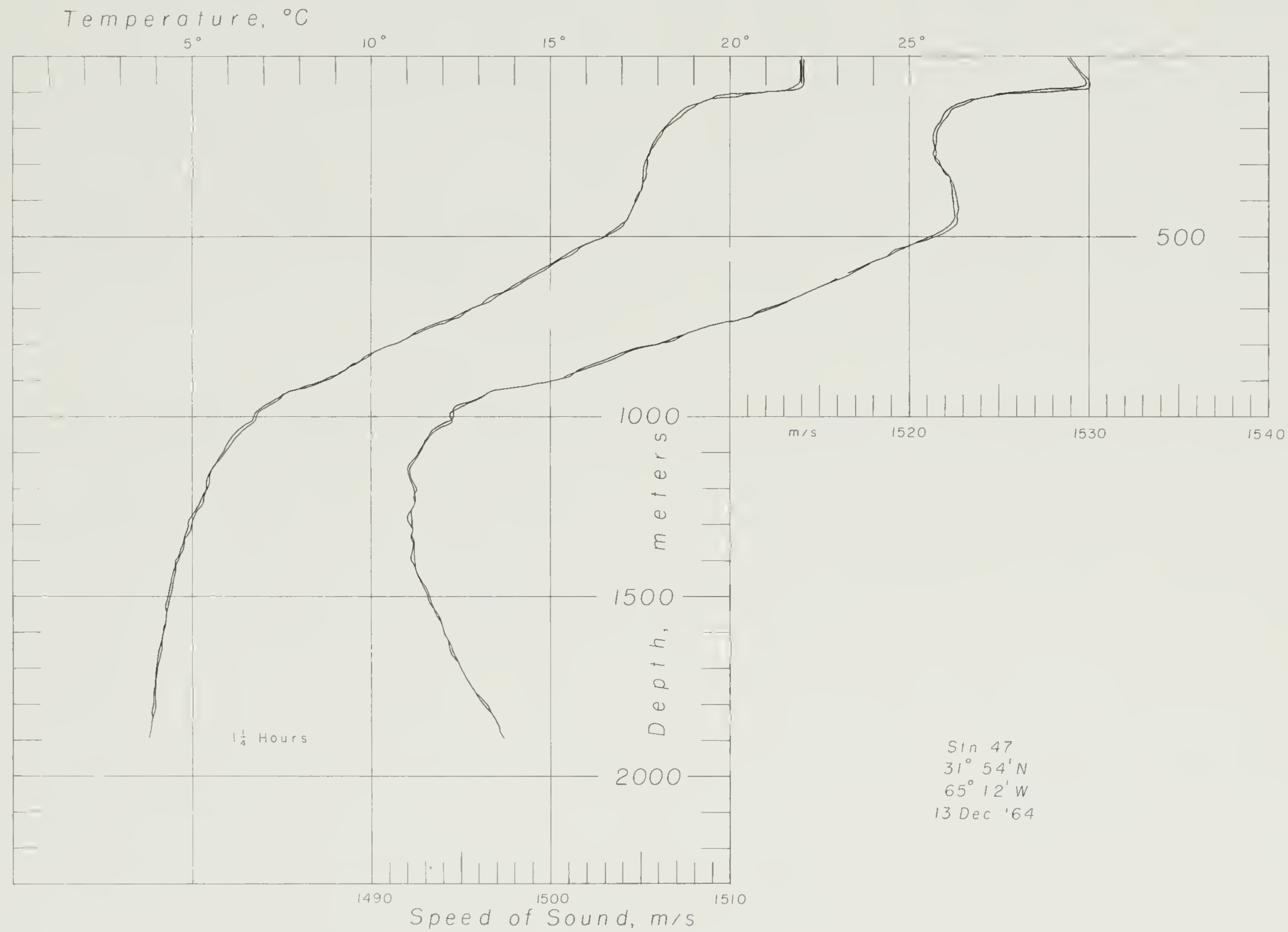


Fig. 66 *Profile Envelopes* – Station 47

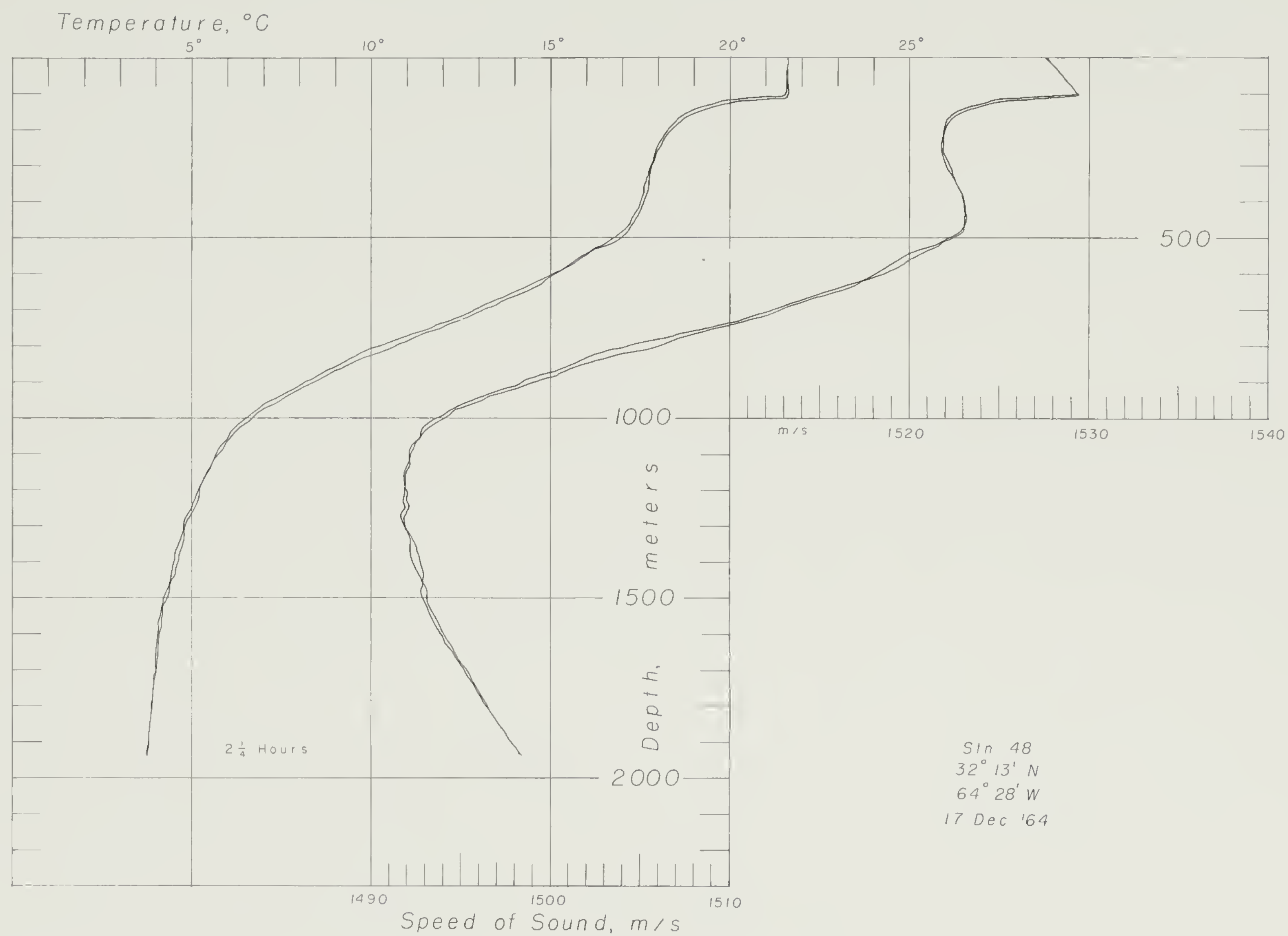


Fig. 67 *Profile Envelopes – Station 48*

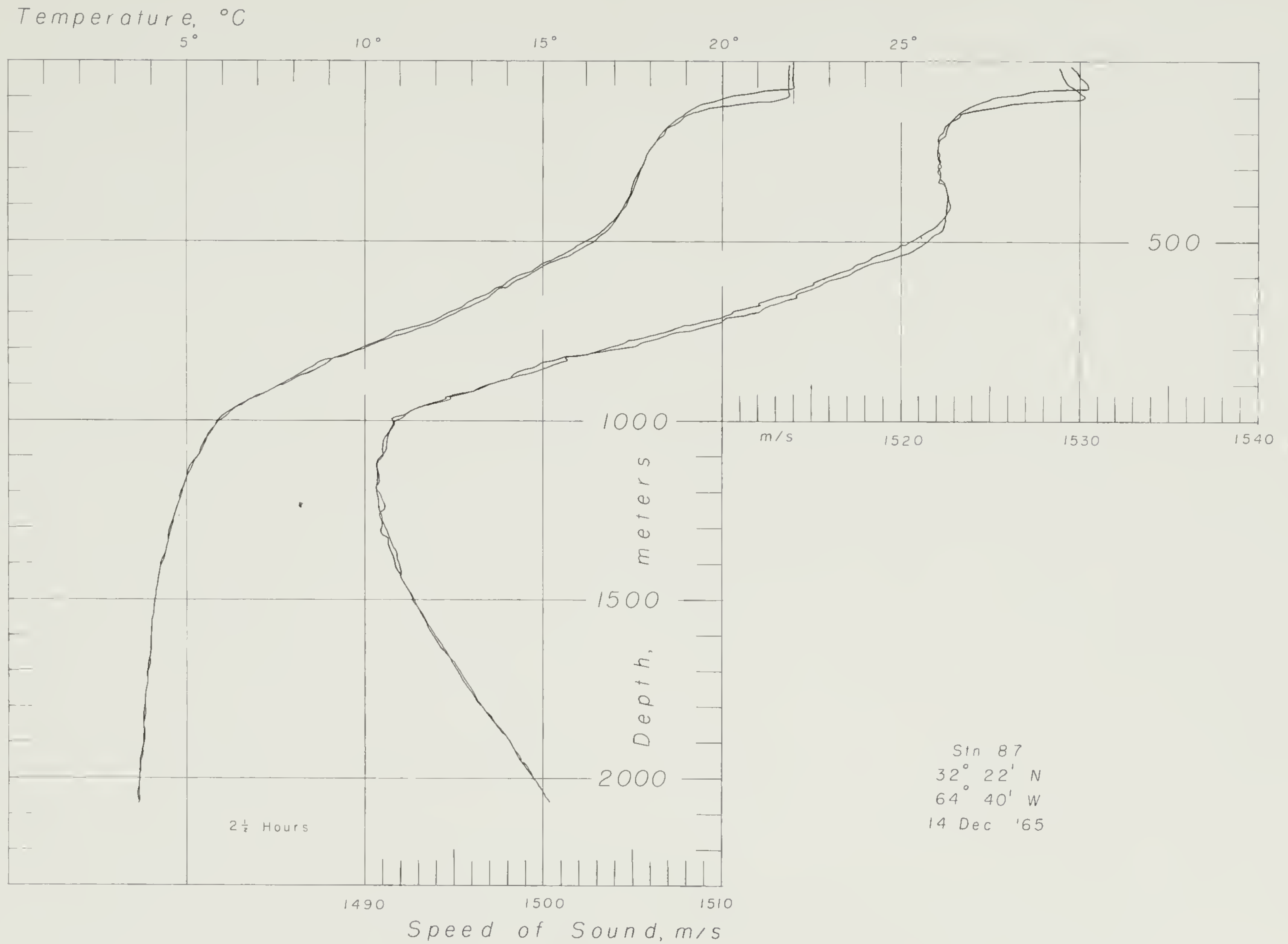


Fig. 69 *Profile Envelopes – Station 87*

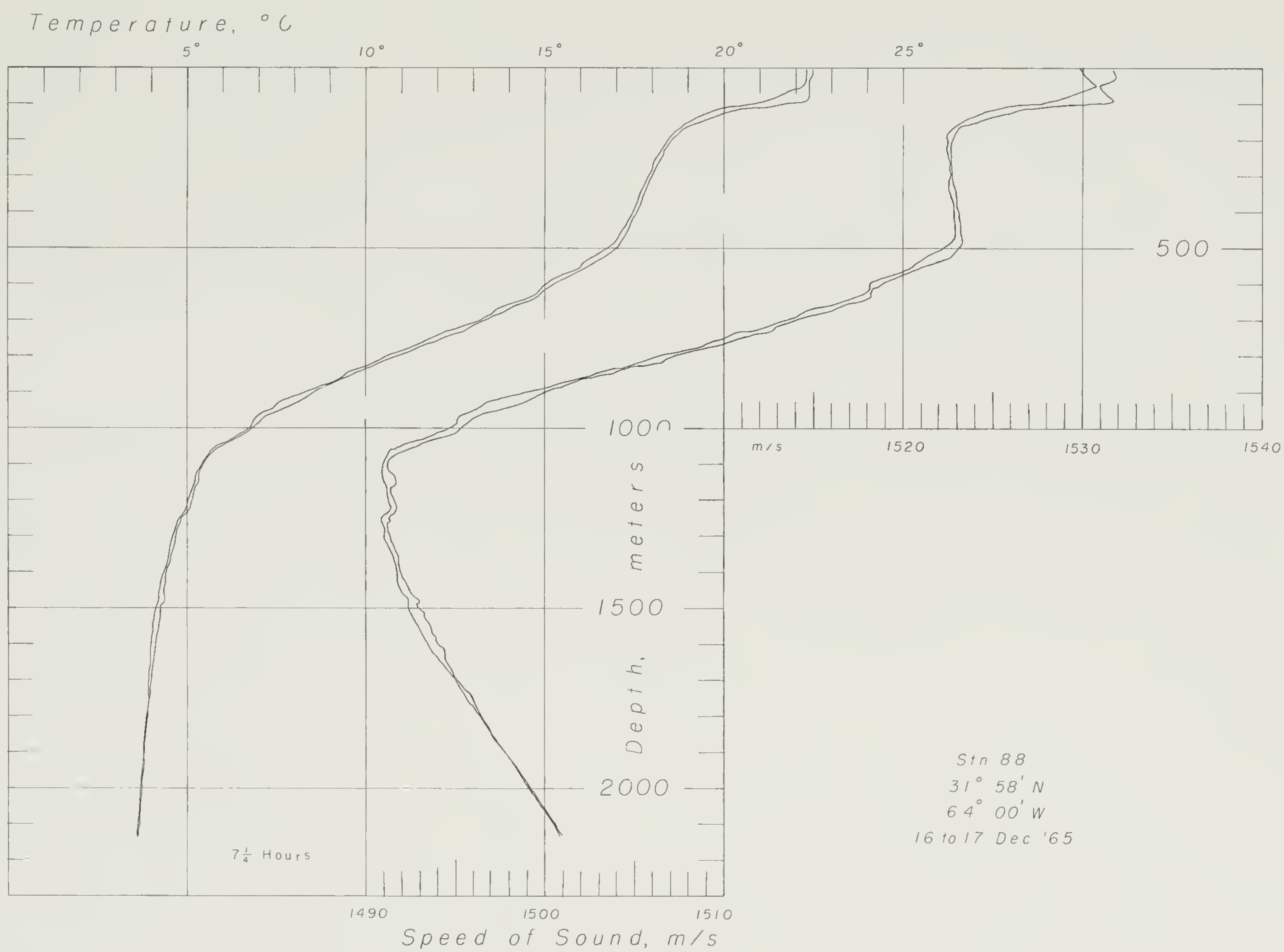


Fig. 70 *Profile Envelopes – Station 88*

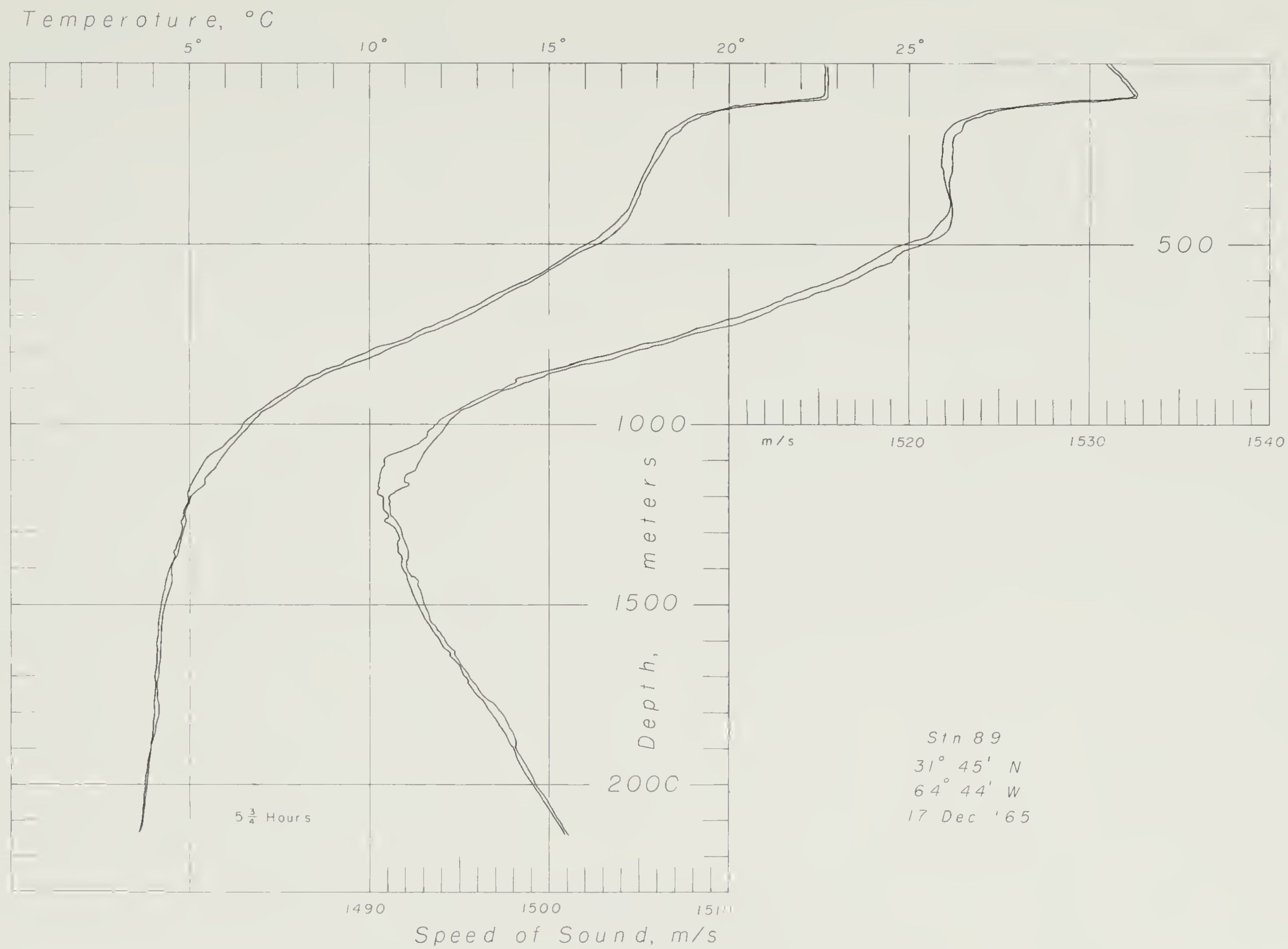


Fig. 71 *Profile Envelopes – Station 89*

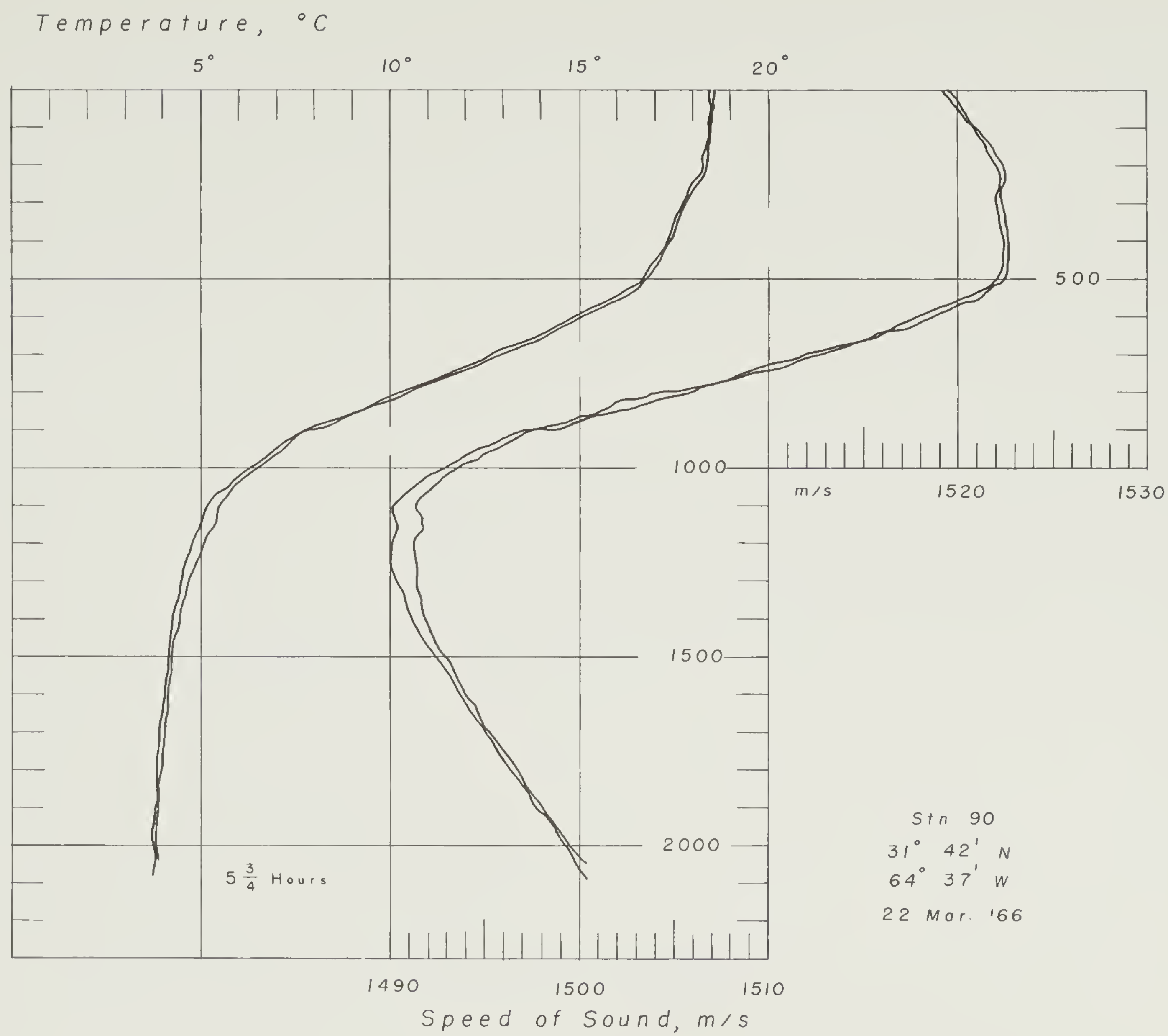


Fig. 72 *Profile Envelopes* – Station 90

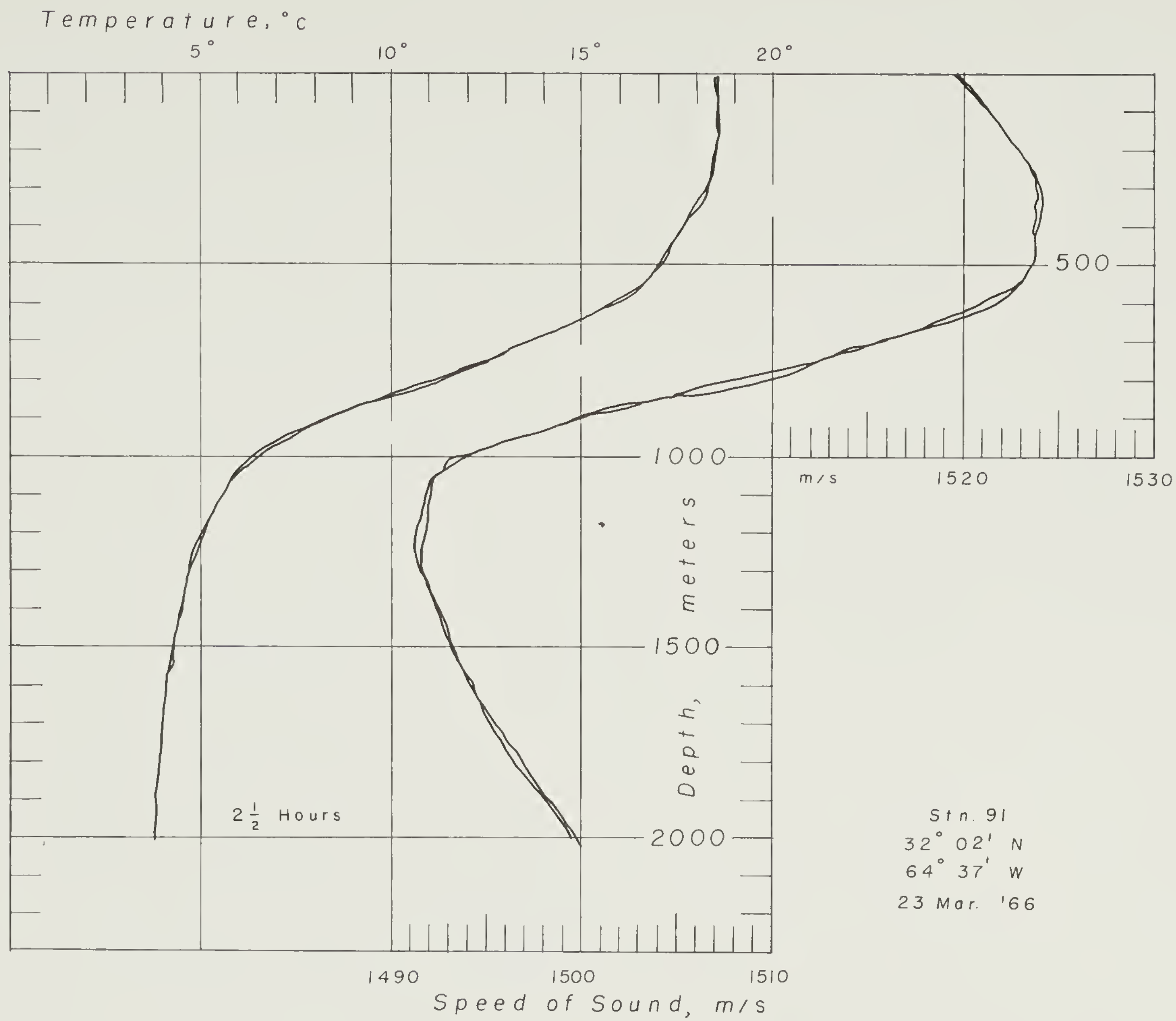


Fig. 73 *Profile Envelopes – Station 91*

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Lamont-Doherty Geological Observatory Columbia University Palisades, New York 10964	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
PRECISION SOUND VELOCITY PROFILES IN THE OCEAN: VOLUME V: SOUND SPEEDS AND TEMPERATURES OF BERMUDA WATERS IN AUTUMN AND WINTER (October 1964 - March 1966)

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Final Report October 1964 - March 1966

5. AUTHOR(S) *(Last name, first name, initial)*
Piip, Ants T.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
October 1969	93	5

8a. CONTRACT OR GRANT NO. Nonr 266 (65) b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) Technical Report No. 7, CU - 7 - 69 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. AVAILABILITY/LIMITATION NOTICES
Distribution of this document is unlimited.
Available from DDC

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Office of Naval Research, Code 468 Washington, D. C. 20360

13. ABSTRACT
A collection of high-resolution, precision simultaneous sound speed and temperature profiles to 2200m depth, and their envelopes for each station is presented for 25 stations in Bermudian waters in the months of October, December and March. The period October to March covers the full range of large seasonal changes in the near-surface waters from summer to winter, while the deep waters remain relatively stable and do not show any definite seasonal changes. For two long constant depth stations, in and below the main thermocline, time series and their power density spectra are shown for sound speeds and temperatures. A table of sound channel parameters at all stations concludes the report. The report emphasizes the variability and short-lived phenomena in oceanic waters around Bermuda.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Oceanography						
Underwater acoustics						
Sound Speed: consecutive, detailed profiles						
Sound Speed: envelopes of consecutive profiles						
Temperature: consecutive, detailed profiles						
Temperature: envelopes of consecutive profiles						
Internal waves						
Internal waves, power spectra						
Sound channel						
Bermuda						
Sargasso Sea						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
________________________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
________________________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
________________________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

DISTRIBUTION LIST

2 Office of Naval Research (Code 468), Dept. of Navy, Washington, D.C. 20360

8 ONR, O.S. & T.G., Code 480, Washington, D.C. 20390
(1 ea. Attn: Undersea Programs (Code 466), Field Projects (Code 418),
Surface and Amphibious Programs (Code 463.)

10 Co, ONR Branch Office, Box 39, FPO New York 09510

1 Oceanographer, ONR, Box 39, FPO New York 09510

1 CO, ONR Branch Office, Pasadena, Calif. 91101

1 CO, ONR Branch Office, Boston, Mass. 02210

1 CO, ONR Branch Office, Chicago, Ill. 60604

1 CO, ONR Branch Office, New York, N.Y. 10011

1 Scientific Dept., ONR Branch Office, San Francisco, Calif. 94103

5 CO, Nav. Ocean. Office, Washington, D.C. 20390
(1 ea. Attn: Library, Code 9330, Code 3310 (C. Moore), Code 9331)

6 Dir., USN Res. Lab., Techn. Info. Div., Washington, D.C. 20390

1 Dir., USN Res. Lab., Sound Div., Washington, D.C. 20390

1 Oceanographer, Office of Nav. Operations, Washington, D.C. 20350

3 Dir., NODC, Washington, D.C. 20390

1 E.S.S.A., Washington, D.C. 20301
Attn: Office of Oceanography

1 Chief, Marine Sc. Center, ESSA, Union Base, Seattle, Wash. 98102

2 National Research Council, Washington, D.C. 20000
(1 ea. Attn: Committee on Undersea Warfare, Attn: Committee on Oceanography)

1 Advanced Research Council, Washington, D.C. 20000
Att: NTDO, The Pentagon, (22846)

1 Dir., National Bureau of Standards, Washington, D.C. 20013
Att: Chief of Sound Section

3 CO & Dir., Naval Undersea Research and Development Center, San Diego,
California 92132

1 Dir., USN Underw. Sound Ref. Lab., Orlando, Fla. 32800

2 CO & Dir., USNUSL, New London, Conn. 06320
Att: W. Martin

Total 208

2 USNUSL Bermuda Research Detachment, FPO New York 09560
Attn: A.D. Cobb

3 Chief, Bur. of Nav. Weapons, Washington, D.C. 20360
(1 ea. Attn: FASS, RU-222)

6 Industrial Manager, USN Dist., Washington, D.C. 20390
(1 ea. Attn: Code 1622B, Code 345, Code 688, Code 370)

1 Chief, Bur. of Yards & Docks, Office of Res., Washington, D.C. 20360
Attn: Code 70

2 CO, Naval Weapons Center, China Lake, Calif. 93555
(1 ea. Attn: Code 753, Code 502)

1 Crd., US NWC, Pasadena Annex, Pasadena, Calif. 91107

1 CO, US NADC, Johnsville, Warminster, Penna. 18974
Attn: NADC Library

1 Crd., US NOL, Acoustics Div , White Oak, Silver Springs, Md. 20910
Attn: Librarian

1 CO & Dir., David Taylor Model Basin, Washington, D.C. 20007

1 CO USN Underw. Ordn. Stn., Newport, R.I. 02840

1 Superintendent, USN Academy, Annapolis, Md. 21402

2 Superintendent, USN PG School, Monterey, Calif. 93940
Attn: Prof. L.E. Kinsler

2 Dept. of Meteorology and Oceanography, USN PG School, Monterey, Calif. 93940

1 Prof. H. Medwin, Dept. of Physics, USN PG School, Monterey, Calif. 93940

3 O in C, U.S. Fleet Numerical Weather Fac., USN PG School, Monterey,Calif. 93940

1 O in C, USN Weather Research Fac., Norfolk, Va. 23511

1 CO, U.S. Fleet Weather Central, Dept. of Navy, Washington, D.C. 20360

1 U.S. Fleet Weather Fac., USN Stn., San Diego, Calif. 92136

1 Library, U.S. Weather Bureau, Washington, D.C. 20000

1 CO & Dir., USN Civil Eng. Lab., Port Hueneme, Calif. 93041
Attn: Code L54

1 CO, U.S.Naval Ship Research and Development Laboratory, Panama City, Fla. 32401

1 US Naval Branch, Oceanographic Office, FPO San Francisco, 96647

1 Commandant (OSR-2) U.S.C.G., Washington, D. C. 20000

1 CO, Coast Guard Oceanographic Unit, Washington, D.C. 20000

1 Army Res. Office, O of Chief of R & D, Washington, D.C. 20000

1 Army Research Office, Washington, D.C. 20000
Attn: Environmental Sciences Division

1 US Army Beach Erosion Board, Washington, D. C. 20315

1 Geol. Dis., Marine Geol. Unit, U.S. Geo. Survey, Washington, D.C. 20000

1 Chief of Sc. & Techn. Pub. Staff, Office of Dir., US C & GS Washington, D.C. 20000

4 CO, Nav. Ship Systems Command, Main Navy Bldg., Washington, D.C. 20360
(Attn: Ships 032, Ships 1622, Ships 1630, Ships 0343)

1 CO, Nav. Ordnance Systems Command, Navy Dept., Washington, D.C. 20360
Attn: Ord 0302

1 CO, Nav. Underw. Weapons Res. and Eng. Stn., Newport, R.I. 02844

1 CO & Dir., USN Ship Res. and Dev. Cntr., Washington, D.C. 20007

1 CO, AUTEC, West Palm Beach, Fla. 33406

2 O in C, Andros Ranges, AUTEC, FPO New York 09559

1 RCA/AUTEC, International Airport, West Palm Beach, Fla. 33406
Attn: A. Townsend

1 Dr. G.A. Rusnak, U.S. Geo. Survey, Mar. Geo. & Hydrol., Menlo Park, Calif. 94025

1 Dr. J.S. Schlee, U.S. Geo. Survey, Woods Hole, Mass. 02543

2 CO PMR, Pt. Mugu, Calif. 95468
(1 ea. Attn: Code 3145, Code 3250)

4 AFETR, Patrick Air Force Base, Fla. 32925
(1 ea. Attn: A.P. Whitmire, Col. USAF: Attn: ETEIS (P. Guzak);
Attn: ETOES (D. Leonard); Attn: SPP NOTU (L.W. Powell.)

1 PAA Development Planning, M.U. 823, Patrick AFB, Fla. 32925

1 RCA Systems M.U. 645. CBO, Patrick AFB, Fla. 32925
Attn: L. R. Whitehead

1 Dir., Bur. of Comm. Fish., US F&W Service, Washington, D.C. 20000

1 Dir. Bio. Lab., Bur. of Comm. Fish., Washington, D. C. 20000

1 Bur. of Comm. Fish., Bio. Lab., Oceanography, Seattle, Wash. 98102

1 Lab. Dir., Tuna Res. Lab., Bur. of Comm. Fish., La Jolla, Calif. 92037

1 Bur. of U. S. F&W Service, Honolulu, Hawaii 96800
Attn: Librarian

1 Bur. of Sports Fisheries & Wildlife, U.S. F&W Service, Sandy Hook Marine Lab., Highlands, New Jersey 07732
Att: Librarian

1 Waterways Expr. Stn., Estuaries Section, Vicksburg, Miss 39180
Attn: Mr. Henry D. Simmons, Chief

3 Dir., WHOI, Woods Hole, Mass. 02543
(1 Attn: J. eckerle)

3 Project Officer, Lab. of Oceanography, Woods Hole, Mass. 02543

1 Dir., Scripps I O, La Jolla, Calif. 92037

1 Marine Phys. Lab. of Scripps I O, San Diego, Calif. 92151

2 Dir., LDGO, Columbia University, Palisades, New York 10964

2 U.S. Navy SOFAR Station, FPO ~~APO~~ New York 09856

1 Dir., Narragans. Mar. Lab., U. of R.I., Kingston, R.I. 02881

1 Bingham Oceanographic Lab., Yale U., New Haven, Conn. 06520

1 Gulf Coast Research Lab., Ocean Springs, Miss. 39564
Attn: Librarian

1 Chairman, Dept. of Meteorology & Oceanography, New York U., N.Y.,N.Y. 10003

1 Dir., Chesapeake Bay Inst., John Hopkins U., Baltimore, Md. 21218

1 Dir., Marine Lab., U of Miami, Miami, Fla. 33146

1 Brown University, Res. Analysis Gp., Providence, R.I. 02912

1 Inst. for Def. Analysis, Comm. Res. Div., Princeton, N. J. 08540

1 Ordn. Res. Lab., Penn. State Univ., University Park, Penna. 16802

1 Dir., Hawaiian Marine Lab., U. of Hawaii, Honolulu, Hawaii 96822

1 Allan Hancock Foundation, University Park, Los Angeles, Calif. 90007

1 Head, Dept. of Oceanography, Oregon State U., Corvallis, Oregon 97331

1 Def. Res. Lab., U. of Texas, Austin, Texas 78712

1 Dept. of Engineering, U. of Calif., Berkeley, Calif. 94720

1 Applied Physics Lab., U. of Washington, Seattle, Wash. 98105

31

1 Documents Div., U. of Ill. Library, Urbana, Ill. 61801

1 Div. of Eng. & Applied Physics, Harvard U., Cambridge, Mass. 01922

1 Central Library, Lockheed-California Co., Burbank, Calif. 91500

1 Techn. Inf. Center, Lockheed M&S Div., Palo Alto, Calif. 94300

1 American Biophysical Res. Lab., Lansdale, Penna. 19446

1 Inst. of Geophysics, U. of Hawaii, Honolulu, Hawaii 96822

1 Great Lakes Res. Div., Inst. of S. & Tech., U. of Michigan, Ann Arbor, Michigan 48103
Attn: Dr. John C. Ayers

1 AVCO Mar. Electronics Office, New London, Conn. 06320
Attn: Dr. H. W. Marsh

1 Dr. C.I. Beard, Boeing Scientific Res. Lab., Seattle, Wash. 98100

1 Dr. F.B. Berger, General Precision Lab., Pleasantville, N. Y. 10570

1 Mr. N.L. Brown, Bissett-Berman Corp., San Diego, Calif. 92101

1 Dr. K.E. Chave, Dept. of Oceanography, U. of Hawaii, Honolulu, Hawaii 96822

1 Dr. T.H. Rossby, Yale University, New Haven, Conn. 06520

1 Mr. J.A. Gast, Humboldt State College, Arcata, Calif. 95521

1 Dr. Harold Haskins, Rutgers U., New Brunswick, N.J. 08903

1 Dr. Wilbur Marks, Oceanics, Inc., Plainview, New York 11803

1 Dr. I.E. Wallen, Asst. Dir., Smithsonian Institution, Washington, D.C. 20560

1 Mr. E.M. Zacharias, Jr., NUS Corp., 9 Keystone Place, Paramus, New Jersey 07652

1 Dir., Bermuda Bio. Stn. for Research, St. George's West, Bermuda

2 Def. Research Member, Canadian Joint Staff, Washington, D. C. 20000

1 Dept. of Geodesy & Geophysics, Cambridge U., Cambridge, England

2 Marine Bio. Assn. of the U.K., The Lab., Citadel Hill, Plymouth, England
Attn: Dr. Cooper

1 New Zealand Oceanographic Inst., Dept. of Sc. & Ind. Res., Wellington, New Zealand
Attn: Library

1 Institut für Meereskunde der Universität Kiel, 23 Kiel, W. Germany
Attn: Dr. Gerold Siedler

2 National Institute of Oceanography, Wormley, Godalming, Surrey, England
Attn: Dr. J. Swallow

50 Defense Documentation Center, Alexandria, Va. 22314

78